H. H. Harris.

Urbana, Ill.

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RAILWAY WONDERS OF THE WORLD

THE RAILWAY PATHFINDERS.

In searching for a route through rugged mountainous country the man with the transit and level often has to be slung on a crazy log platform over a raging torrent.

Railway Wonders of the World

By

Frederick A. Talbot

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Illustrated with Colour
Plates and Photographs

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Railway Wonders of the World

Foreword

NO invention since the march of civilisation began has changed the map of the world so completely as that of George Stephenson. No other production of the human brain has introduced such a powerful force of conquest, development, expansion, and settlement as the railway.

The opening up of new countries and territories by the steel highway constitutes the greatest romance in the world's history. It has shrunk time and distance, has created new cities, has brought aridity to fertility, has peopled the wilderness, has subjugated the mountain, and has let light into the forest. Swamp and desert, sea and snow, mountain and gulch have been vanquished in its irresistible advance. The brain and blood, thew and muscle, nerve and soul which have been sacrificed in this conquest never can be forgotten; the men who fell in the great effort to drive this great civilising influence forward have built an imperishable monument which time cannot destroy.

The plotting and building of the great railways of the world make one long story of exciting adventure, exacting hardship and toil, and of prodigious difficulty overcome. In the narration of this romance I have been assisted by many of those who have been engaged in weaving this network of steel along which flows the commerce of the world.

The railway constitutes a prolific field for inventive effort. There are various side issues associated with the main

problem of building the road, and these have been incorporated. The primitive tools, the pick and shovel, have been superseded by wonderful time- and labour-saving mechanical devices, which expedite and facilitate the work of the builder. Then the cry for additional railway facilities, which is raised on all sides, has been responsible for the production of improved, quicker, and cheaper methods of operation. This question has stimulated the evolution of bigger and more powerful locomotives, larger freight wagons, more capacious passenger coaches: the cry for the annihilation of time and distance has animated the struggle for higher travelling speeds with safety. All these factors are described in due course.

During the past few years the struggle for supremacy between steam and electricity as a motive power has become exceedingly acute. The attempts which are being made, and the successes achieved, in this direction have received their meed of attention.

In the early days the towering mountain range was considered a well-nigh impassable barrier. Nowadays the engineer does not worry himself as to how to climb over the obstacle: he plunges boldly through its base. Or he lays a peculiar track up its precipitous flanks, whereby passengers may be conveyed in safety to otherwise inaccessible eyries, to gaze upon majestic panoramas of glacial scenery.

The turbulent, wandering river, the mud-flat, the dismal desert, and the hurricane-ravaged islet worry the technical mind sorely, and marvellous ingenuity is displayed in their conquest. When all known methods of meeting the situation become exhausted, and prove futile, then new ways and means have to be devised. As a result many startling wonders are wrought.

The present generation has become so accustomed to the railway that it regards it somewhat with indifference. Yet it is difficult to realise how the world rolled along before George Stephenson's invention appeared upon the scene. If this planet were robbed suddenly of all its railways, a catastrophe almost as terrible as that arising from the deprivation of its sunlight would be precipitated. This familiarity has served to obscure the glamour and romance associated with construction.

Obviously it would be impossible to relate the incidents and episodes associated with every one of the 800,000 miles of steel track enmeshing this globe. I have made merely a selection of the great roads between the two Poles, some of which perhaps are better known than others.

Technicalities have been simplified purposely, as this work is not written for the master of craft, but more particularly for those generally interested in railways, financially or otherwise. Particular insistence has been centred upon the many peculiar forms which the resistance of Nature has assumed to frustrate puny human endeavour, and the methods elaborated to cope with unusual situations.

Notwithstanding a century's progress, railways are yet in their infancy. New construction is more active to-day than ever. Still, while new lines are being thrown out in all directions, and in accordance with the most modern and approved principles of railway engineering, the pioneer roads are not being neglected. Competition is demanding their overhaul and improvement, and in many instances a steel highway has been changed out of all recognition in the attempt to eliminate the blunders and mistakes made in the first place. In fact, more money is being expended in the reconstruction of existing railways than in the prosecution of new undertakings. This transformation forms quite as attractive a story as that of original construction, and therefore is deserving of inclusion among "Railway Wonders of the World."

RE-ALIGNMENT OF THE CANADIAN PACIFIC RAILWAY THROUGH KICKING HORSE PASS.
View showing the amazing location of the new line and spiral tunnels. The old line runs through the centre. The new line doubled the distance (8.2 miles), but halved the grade (2.2 per cent.—116 ft. per mile).

Spending Millions to Save Minutes

MANY GREAT RAILWAYS IN DIFFERENT PARTS OF THE WORLD HAVE HAD TO BE RECONSTRUCTED TO MEET MODERN REQUIREMENTS

IN the early days of railway building engineers were given very few opportunities to display their genius and skill. Money was scarce, and the craving for this system of transportation among the public, after it had survived the first wave of prejudice, was so insistent that the lines had to be laid with the utmost possible dispatch. Accordingly, the lines were laid without any regard to gradients and curves. If a hill stood in his path the engineer did not pause to drive his way through the obstruction; he either ran round or over it. A line built upon this system certainly was an amazing piece of work, as it followed the inequalities of the ground, and twisted in loops and curves like a drawn-out spiral spring.

In the course of a few years, however, the original lines broke down completely under the increased traffic, or were in danger of extinction by better-built and later rivals. In frantic haste the engineer was seized and told to straighten out the original track, so as to permit faster running and heavier loads with less expense.

So far as Great Britain is concerned, there has been little evidence of elaborate remodelling. The railway was a product of this country, and the men who evolved the invention, as a result of their years of patient experimenting, were more familiar with the possibilities of this method of transportation than those who embraced it afterwards. Some of our railways, however, have short sections of steep grades and sharp curves which have not been abolished yet. The most striking instance, perhaps, is afforded in Cornwall, where, for year after year, the Great Western Railway found the tortuous rising and falling line built by Brunel a heavy drag

upon its service. The expresses were able to thunder over the 225¾ miles between London and Plymouth at a speed of 54.9 miles an hour; but on the continuation of the journey through Cornwall to Penzance the speed dropped to 30 miles per hour. The development of the Cornish health and pleasure resorts demanded higher speed between Plymouth and Penzance, as well as heavier trains. This, however, was impossible under existing conditions, so the company, without more ado, set to work to

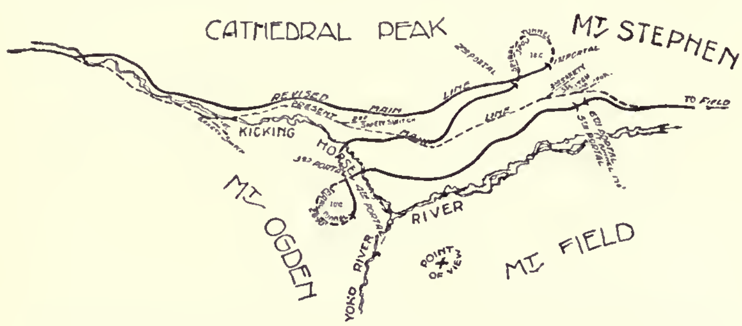

DIAGRAM SHOWING THE RE-ALIGNMENT OF THE CANADIAN PACIFIC RAILWAY THROUGH KICKING HORSE PASS.

pull out Brunel's line: flattening his grades, easing his curves, rebuilding his bridges, and laying a double track. In this manner it has been possible to bring the Cornish tail up to the standard of the rest of the system. But the expense has been enormous.

But this work of remodelling is revealed in its most compelling form in other countries, especially in the United States and Canada. In both instances the first lines were laid hurriedly and cheaply in order to open up the country, or to link together towns which were isolated hundreds of miles apart. The sleepers were thrown on the ground and the rails "tacked" to them. The engineer, having plenty of elbow room, wandered hither and thither with his permanent way, in order to complete construction quickly.

The majority of these early roads are in service to-day, but so improved as to defy recognition by those who carried them out in the first place. Summit levels have been reduced by driving tunnels at lower elevations, so as to avoid tedious, laborious climbs and waste of engine power; chords have been cut across loops to reduce distances; bridges have been thrown across rifts and ravines which originally were avoided by detours; and banks have been lowered. Mr. E. H. Harriman, when he was called before the Interstate Commerce Commission, expressed the opinion that every American railway would require to be rebuilt, and it is estimated that over £200,000,000 has been expended in the task of reconstruction. The expense of overhauling many of the lines has exceeded the initial cost of building them. The American railway controllers have not been by any means parsimonious in their enterprise. Miles of lines have been abandoned in favour of easier new routes, and the vigilant traveller, as he wanders about the continent, can see long lengths of these derelicts rusting in the sand, overgrown with weeds, or undergoing burial by rock and land slides.

Nowadays curves and grades are voracious. The waste they represent is tremendous. There is a single curve on a busy continental road just outside Chicago which represents a dead loss of £40 a day to its company. Another line lifted dips and lowered rises in the permanent way, as well as straightened out curves, for a distance of sixty miles, so as to secure high speeds and to hold its own against competition. The Lake Shore and Michigan Railway was handicapped sorely by the meandering of 1½ miles of line near La Porte, Indiana. The engineers overcame the drawback by pulling the faulty section to pieces and laying a straighter and faster length of track; but it cost them £50,000 to achieve their end.

In connection with this reconstruction

RE-ALIGNING THE FIELD TO HECTOR SECTION OF THE CANADIAN PACIFIC RAILWAY.

Field, the western portal to Kicking Horse Pass, and bottom of the "Big Hill." The railway hugs the foot of the mountains.

work some startling and prodigious achievements have been and are being consummated.

The "Big Hill."

When the Canadian Pacific Railway was built from coast to coast the practice which had governed the building of the first American transcontinental road was followed: the line was flimsily built, the governing considerations being completion in the minimum of time with the lowest possible cost. But the inevitable happened. The line was overtaxed, and overhauling had to be taken in hand without delay. The most serious obstacle was in the Rocky Mountains. Here the constructional engineers, in order to avoid expense, had introduced a bank 4.1 miles in length with a grade of 4.5 per cent.—237.6 feet per mile. It was so steep that it became known throughout the system as the "Big Hill." It arose from the suddenness with which the ground falls away through the Kicking Horse Valley between Hector and Field.

Negotiating the Big Hill.

The Big Hill came to be dreaded by all the drivers who ran through the Rockies. When they reached the top of the bank they shut off steam and tried their brakes. They descended by sheer gravity, applying the brakes now and again to keep the train in check. Switches were introduced here and there, and the switchman listened attentively for the approaching train. If the whistle tooted a certain signal the main line was left open, but if the whistle blared out another cry the switchman knew that the train had got out of control; he promptly opened the switch, and turned the runaway into a bank. One driver who had handled the heavy freight trains which go down to Vancouver gave me his opinion that "running down the Big Hill licked a lottery to fits. You were certain to hit the bottom of the valley all right, but whether via the railway tracks or in a bee-line through the air it was impossible to say!" As may be supposed, derailments were by no means infrequent.

How the "Overland" climbed the Big Hill.

While the run down the Big Hill was full of excitement to the freight train, the ascent was trying to the Overland mail. The train, as a rule, weighed about 710 tons, and a bank such as this was too much for a single engine. At Field they kept a full stable of "pusher" locomotives, monsters of their day, of the 2-8-0 class, and turning the scale at 74 tons apiece. Two, four, five, and even six engines have been requisitioned to lift the mail over that hump, and the roaring and belching as the locomotives struggled up at a crawl of five or six miles per hour transformed the rock-strewn, snow-walled Kicking Horse Valley into a veritable Inferno. When the line was first built it was indifferently ballasted, but the Big Hill became the best-laid piece of track in the mountains—it became packed with the half-consumed coal and ashes ejected from the locomotives as they snorted and struggled up the incline under their loads.

The "Overland" going up the Big Hill certainly was an impressive spectacle, but it was poor business. The railway company were aware of this fact; just how much it cost them to handle the trains over this fearsome bank only they themselves know. At last the management decided to eliminate this drag upon the high efficiency of their system. "The railway must be realigned through the Kicking Horse Pass. Never mind what it costs." This was the official ultimatum to the engineers, and Mr. J. Schwitzer sallied out to fulfil the commands. He searched every nook and cranny of this wild, forbidding stretch of the mountains, and finally came home with the best scheme that engineering science could offer to deal with a difference of 952·5 feet in a handful of 4.1 miles.

It was a daring proposal, and it introduced an ingenious solution of a difficult

problem, which, though common in Europe, was quite new to the American continent. He decided to use the same device as Hellwag had adopted to secure extrication from a similar tight corner on the St. Gotthard railway: the spiral tunnel. in length, and therein the train completes a corkscrew twist, emerging into daylight almost directly over the portal, some feet below, by which it entered the mountain. It then runs along the Kicking Horse Valley, crosses the river, doubling back upon

LOOKING THROUGH THE KICKING HORSE GULCH.
The new line of the Canadian Pacific in the foreground.

The Kicking Horse Gulch did not give much elbow room for the work; but Schwitzer outlined a plan which, although it doubled the mileage through the pass, yet reduced the gradient exactly by one-half. The scheme was daring, but was carried out. In entering the pass from the west the railway plunges into a tunnel 170 feet long under Wapta Mountain. Then it swings away from the old line, which traverses the centre of the pass, cuts across the Kicking Horse River, and burrows into the base of Mount Ogden on the opposite side of the ravine. This tunnel is 2,012 feet itself, running almost parallel with the first part of the line, but in the reverse direction, to gain the opposite side of the valley once more, where it penetrates Mount Stephen to describe another elliptic curve in a tunnel 3,184 feet long. Regaining daylight, the line doubles back on itself once again, until it meets the point where the second line in the zigzag crossed the old line, which is now rejoined. It is a railway maze, the line doubling upon itself twice and crossing the river twice, in order to reduce the severity of the incline.

The total length of the new line is 8.2 miles, and in no place is the gradient heavier than 1 in 45.45 feet. In the spiral tunnels, which have a curvature of 573 feet radius, it was found possible to give an easy grade. In the completion of the work 700 men found employment. The two spiral tunnels were driven from each end simultaneously, compressed air rock-drills being used to break down the rock, which, being of silicious limestone, somewhat facilitated rapid progress.

The Spiral Tunnels.

Here and there searching difficulties were encountered. The rock was found to be fissured, so that water gained an entrance into the workings ; but the pumps proved able to cope with the inflow. In other instances treacherous layers of shale were struck, and heavy timbering had to be adopted, and a concrete lining afterwards completed. When the work was commenced hand labour was used for removing the spoil dislodged by the blasts, but this proved so inadequate that powerful steam shovels were brought up, and they kept pace with the drills and dynamite. These shovels were driven by compressed air, so as not to foul the workings.

Work was maintained at high pressure the whole time, the tunnels being brilliantly lighted, so that excavation might continue night and day uninterruptedly, while in the open workings oil flares served sufficiently to illumine the scene through the hours of darkness to enable progress to be maintained. At times there was a shortage of men, especially among the unskilled labourers, who, after staying a short while, and having amassed a tempting nest-egg, hied on their way to the Pacific coast, where they could command higher pay for the sweat of their brow. Despite these hindrances, however, the task was completed in about nineteen months, by which time over £250,000 had been expended, of which sum £50,000 vanished in smoke alone, as 1,500,000 pounds of dynamite, sufficient to fill seventy-five box cars, were consumed. But the reconstruction has repaid the Canadian Pacific Railway Company. Whereas formerly a battery of powerful locomotives was required to handle a train weighing 710 tons, now a train weighing 980 tons can be handled easily by a double-header at a speed of 20 miles an hour. Not only is the cost of working over this section reduced by over 60 per cent., but there is an improved time schedule, while a greater degree of safety is secured to the travelling public.

£50,000 for Dynamite.

When the engineer is called upon to thread a forbidding rugged mountain range, he generally takes advantage of the natural paths to carry him through the obstacle. A river is an ideal channel, although it may possess the drawbacks of wandering apparently aimlessly among the precipitous crags, making sharp twists and bends. The latter, however, can generally be circumvented by driving short cuts with tunnels across the loops. As a rule, however, the waterway is constricted, and will occupy the whole floor of the gorge, while its level fluctuates wildly. In the spring it is a babbling brook rolling peacefully along ; but in the late summer, when the torrid sun melts the snow on the peaks, causing rivulets and creeks to dance down the cliff sides into the main channel, then the waterway rises suddenly to a high level, and tears along fiendishly, sweeping all before it.

The River Difficulty.

Such a situation faced the engineer when he was called upon to carry the railway through Eagle Canyon, Colorado, for the Denver and Rio Grande system. He searched the ravine, and found a convenient ledge, which he seized here and there, smoothed it off, and laid down his metals. It is a V-shaped rift, with the mountains hurrying skywards on

Railway through Eagle Canyon, Colorado.

either hand from the waterway. But the ledge afforded a foundation. Where it was interrupted by knots of rock the engineer either blew them away to the width he desired or tunnelled them—whichever was easier, cheaper, and quicker. He strengthened his rampart where it was weak with a massive stone wall, and entertained no apprehensions that his work would be washed away when the turbulent Eagle River rose in flood.

But in course of time the single track used for both up and down traffic became inadequate. The Goulds got control of the line, and, what was more, at the end of thirty odd years achieved the height of their ambitions: they had a connection running to the Pacific — the Western Pacific Railway. A new source of traffic was tapped, to carry which rendered a second pair of metals through Eagle Canyon imperative.

The engineer was commanded to double track the line for six miles through the gulch. It seemed a simple task to fulfil, but he had different notions. The existing ledge was just wide enough to take the one pair of rails and no more. The shelf could not be widened very cheaply, as it meant trimming back the toes of the cliffs somewhat heavily. There was another similar though not so well defined ledge on the opposite side of the river. He decided to press that to his aid.

Double Tracking through the Canyon.

The first thing was to control the waterway, to keep it within bounds, so that it could not thunder, foam, and tumble where it pleased. He threw up a massive masonry wall. In so doing he drove the water back somewhat, but to guard against all risk, the existing ridge was fortified with new masonry here and there. The result is that to-day the Eagle River ripples or rushes, according to its mood, along a big ditch, fenced in on either side by a heavy, well-built masonry wall, which defies the waterway's most violent outbursts of frenzy.

By being compelled to take to the opposite side of the river for his second line, the engineer was brought face to face with another obstacle. The cliffs are steep, but here and there they are scarred by wide gullies filled with loose rubble and detritus. These are the tracks of avalanches, rock-slides, and landslips. They are well defined, and the movements follow these passages every year, as certainly as night follows day. These destructive forces had to be avoided; accordingly the engineer swung his line across the waterway to the existing shelf, widening it out to suit his purpose. At places the ledge was interrupted by a spur which dropped sheer into the water. If it was not too formidable, the engineer blew the mass out of the way; in other instances he tunnelled it.

Dodging the Avalanche.

It was a stupendous task, and by the time the two sets of rails had been laid a distance of five miles £100,000 had been spent. Yet it was considered to be well invested, because it enabled double the traffic, at least, to be handled through the rift. As the engineer, in building the second track, kept down the grade, and made the curves easy, it was selected for eastbound trains, as there was less resistance to the locomotives, which had to overcome a rise of 116 feet as compared with 174.24 feet per mile on the old line. Originally it was intended to rebuild the pioneer track with flatter inclines; but as its steep grade is in favour of westbound traffic, it has been retained.

Five Miles, £100,000.

This selfsame system has groaned for years under the handicap of a big hump which was introduced in the early days between Tucker and Soldier Summit, in order to carry the railway across the Wasatch Mountains, Utah, into Salt Lake City. It was a serious obstacle to economic and rapid operation, since the drag is seven

DOUBLE-TRACKING THROUGH EAGLE CANYON, COLORADO.

The second pair of metals had to be laid on the opposite side of the river—on the right—for five miles at a cost of £100,000. The "Limited" is descending the old track.

miles in length, and the gradient is 4 per cent.—211 feet per mile. In other words, the train had to rise 12 inches for every 25 feet it advanced.

Stalls of pusher and header locomotives were kept in readiness at the bottom of the hump to give a passing train a lift. When the "Fast Denver Limited" was being put over the bank the spectacle was thrilling. This magnificent crack train is made up of eleven heavy Pullman cars, and in order to maintain the speed and to keep time up the hill, five engines had to be called into service, four monsters tugging for all they were worth, with a fifth pushing just as hard at the rear. When the rails were greasy under snow or drizzling rain, even this collection of engine power experienced a stiff struggle to keep up the regular speed.

The hump was tolerated until the close of 1912, when President Bush and Vice-President Brown, of the railway system, laid their heads together and decided to cut it out at all costs. Such drastic action was imperative. The Western Pacific was open, giving Denver a new outlet at San Francisco.

The business over this new artery is increasing rapidly, and at the same time the mineral traffic is rising by leaps and bounds, owing to the enormous shipments of coal and coke from the Utah mines to the Salt Lake, Nevada, and Montana smelting and reduction plants, which have become busier owing to the provision of

improved transport facilities offered by the Western Pacific Railway. The Denver and Rio Grande Railway plays a prominent part in this development, so the overhaul of the Soldier Summit Hump on its main through line could not be delayed.

In response to official instructions, the engineers located a new route, which, although increasing the distance between the two points from seven to fifteen miles, at the same time presented half the grade, and a reduction in the curvature. The administration decided to accept this solution, and a contract was made immediately for the cutting out of the hump. By means of the new track the rise is brought down to only 1 in 50—the maximum on the Denver and Rio Grande main line system.

The cost of these fifteen miles of new line was unavoidably heavy, the contract with the Utah Construction Company, one of the great railway building forces of the Middle West, being for £300,000, or £20,000 per mile. The railway, however, called for a double, instead of a single line, the old road being abandoned completely. The revision work was of an exceedingly arduous character, the revised route running through heavily undulating country. Although no bridges were necessary, several concrete arches were required, together with one tunnel, 255 feet in length. The track is heavily ballasted, and is laid with 90 lb. steel rails.

One of the most striking instances of the endeavour to straighten out a railway built

DOUBLE-TRACKING THROUGH EAGLE CANYON, COLORADO.
View of the shelf prepared for the new track, showing heavy masonry wall to keep the river within bounds.

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in a hurry was on the Delaware, Lackawanna and Western Railroad. As in the case of other systems of to-

The Lackawanna Cut-off.

day, this railway had a modest beginning, but as time progressed it threw out additional tentacles; absorbed short lines that stood in the way; and these threads were welded into a homogeneous whole. An intricate network of lines stretching from the Great Lakes to the Atlantic seaboard, and penetrating the rich coal areas of the Eastern States has been woven in this manner.

The district threaded is very mountainous, and the original engineers ran their lines through the natural cracks in the mountains, paying no regard to the big detours, and troubling little about grades and curves. The result was that when later railways penetrated this rich territory with straighter, flatter, and shorter routes the original system found its traffic threatened.

This menace assumed serious proportions. Between Hopatcong and Delaware Gap the company possessed

Sharp Curves and Heavy Gradients.

as bad a stretch of $39\frac{1}{2}$ miles as could have been built. It abounded in curves which, in the aggregate, described fifteen and a half circles, representing nearly 13 miles, while grades ran up as high as 60 feet per mile. These conditions limited the load per locomotive to thirty cars, as compared with seventy-five similar wagons which were hauled by one engine on competitive roads.

Such a disadvantage could not be tolerated. Accordingly the engineer was called in and told by President Truesdale to find a shorter cut between the two points at any cost. Accordingly a new route was discovered showing a saving of 11 miles, the wiping out of four and a third circles of curvature, and a grade reduction to 29 feet per mile at an estimated cost of approximately £2,000,000.

Despite the alarming proportions of the cost, the engineer estimated that one hour could be clipped off the running time of the goods trains, and twenty minutes off the schedule for the expresses; and that the saving in working and maintenance charges would be sufficient to defray interest on £2,100,000. Thus the engineer was on the right side, and accordingly was told to "go ahead."

It was a daring scheme. Here were $39\frac{1}{2}$ miles to be wiped out of existence and a new line, $28\frac{1}{2}$ miles, to be built at something like £66,000 per mile.

£66,000 per Mile.

Mr. G. J. Ray, the engineer-in-chief, ventured to me his opinion that this "work is the heaviest per mile of any large railway ever undertaken in the United States." The earth and rock excavation averaged about 500,000 cubic yards per mile.

This will afford some idea of what was entailed in carrying out the Lackawanna Cut-off, as it was called. There was a heavy premium on the services of dynamite and steam shovels. The cuts were amazing; the embankments startling. There was one wide valley among the tumbling ridges, which ran transversely to the location. "How was that to be filled?" asked the farmers in the depression. "By an embankment," retorted the engineer, and before the agriculturists in the valley realised the significance of this work, overtures were being made to buy out their farms. The base width of an embankment ranging from 75 to 110 feet high would be too great to be accommodated in the ordinary right-of-way, while, had the railway purchased just the necessary strip of land, such little pieces of farms would have been left that they would not have been worth cultivation. The farmers accordingly were compensated with big cheques for their property, and went off to pastures new, while the railway engineers set to work building up the massive ridge of the Pequest Fill, with over 6,600,000 cubic yards of spoil.

The plant turned to work on this cut-off represented a fortune in itself. One contractor had sufficient engines and cars to run a small railway, and he valued them at £40,000. Every possible device which would hasten construction, and save time and labour, was adopted. The ridges were not built up in the ordinary dumping way. A ropeway was stretched across the ravine, and from this was suspended a track laid on sleepers. The engine backed the loaded trucks on to this swinging track to be emptied. At other points towering timber trestles were erected. Rails were laid on top, over which the ballast cars rumbled and dumped their loads until every sign of the timber had disappeared beneath the big earthen bank.

The cuttings were as stupendous as the embankments. There is one as deep as the Pequest Fill is high, the trains hurtling along a huge trench 100 feet deep. In one instance the builders drove their way for half a mile through granite, wherein the persuasive efforts of dynamite were required to dislodge 1,000,000 cubic yards of rock. Some of the blasts were strikingly large. In a single detonation 40,000 lb. of dynamite shivered a complete mountain nose.

CUTTING OUT THE SOLDIER SUMMIT HUMP ON THE DENVER AND RIO GRANDE RAILWAY.
By this work a rise of 105, instead of 211 feet, per mile is secured.

Smaller blasts, ranging up to 1,000 lb., were almost of hourly occurrence. In fact, the demands for this rending and splitting agent were so steady and large that a factory was set up near Hopatcong for its manufacture upon the spot, supplies being delivered as required by the wagon load. By the time the track was opened for service over 5,000,000 lb. of dynamite had been used.

It was cutting and embankment, with stretches of bridging, for every yard of the way. Over 13,000,000 cubic yards of earth and rock were dislodged from the cuttings to build up the embankments, which

THE "FAST DENVER LIMITED" CLIMBING SOLDIER

The train had to rise one foot in 25 feet, and to maintain the scheduled speed four header and one pusher
by six miles, has reduced the grade to 1 in 50.

SUMMIT, WASATCH MOUNTAINS, UTAH, U.S.A.

engines were required. A new double-track detour has been made which, although increasing the distance
The 15 miles of new line cost £300,000.

absorbed some 15,000,000 cubic yards of spoil, the balance of the material being hauled from ballast pits which were opened at convenient points. Then sixty-five bridges were built over rivers and roads, ranging from a single arch of 33 feet span to a structure 1,450 feet from end to end over the Delaware River. This latter is the largest structure on the cut-off, handsomely wrought in concrete, comprising five spans each measuring 150 feet, two of 120 feet, and two small arches over the railway tracks, each of 33 feet, with the metals laid 65 feet above the ordinary level of the river. Paulins Kill Bridge is the second largest. It is 1,100 feet long, built up of five 120-feet spans and two 100-feet spans, with the rails 115 feet above the level. The bridges consumed 225,000 cubic yards of concrete.

The expenditure of £2,000,000 for a mere 28½ miles conveys some idea of the extremities to which the older American railways are forced to go in order to retain their traffic. In this instance the Lackawanna has more than recouped its losses, and is, in fact, placed at an advantage as compared with its rivals.

A 16¼ TON BLAST ON THE LACKAWANNA CUT-OFF.
5,000,000 lb. of dynamite were used in this reconstruction work.

The Chicago, Milwaukee, and St. Paul Railway embarked upon a striking piece of grade revision across the Des Moines River Valley near Madrid. Seven miles of existing line were scrapped in favour of a new line five miles in length, whereby 791 degrees of curvature were eliminated and the gradient lowered by 96 feet. The new track has been driven as straight as engineering ingenuity can contrive. Where the line crosses a deep chasm an artificial mountain was created so as to preserve

The hillside (granite) before the blast.

After the blast: 20,000 tons of disintegrated granite.

THE EFFECTS OF 16½ TONS OF DYNAMITE USED IN THE WORK ON THE LACKAWANNA CUT-OFF.

the grade for a double track, while the river itself is spanned by a dizzy bridge of steel, the feature of which is that the permanent way is ballasted, instead of the rails being laid on longitudinal timbers. In this re-alignment the stations were moved two and three miles across country from the old to the new road.

When the railway invaded Australia the engineers were confronted by some abnormal differences in level within short distances, owing to the abrupt configuration of the mountain flanks. This was especially the case in New South Wales and Western Australia, where the Blue Mountains and the Darling Range respectively had to be overcome. But the natural difficulties were not the most serious: official ignorance was a far heavier millstone around the necks of the railway plotters, and some very quaint ideas were entertained by the powers that were concerning the operation and possibilities of the railway locomotive. It took Mr. John Whitton a long time and considerable detailed correspondence, as well as explanations and diagrams, to convince his superiors that a railway engine really was superior to the horse in haulage work!

The trouble arose over the question of carrying the railway onwards from Penrith over the Blue Mountains to Bathurst. A sheer drop of 470 feet had to be negotiated. The engineer-in-chief wanted a tunnel, or series of tunnels, to preserve the grade; but burrowing was expensive, and it was ruled out of court. The engineer stuck to his ideas, however, and so pestered officialdom that he got his way up to a point, but was given a limit of £20,000 per mile.

BUILDING UP THE PEQUEST FILL ON THE LACKAWANNA CUT-OFF.
This enormous embankment absorbed over 6,600,000 cubic yards of material.

Such a stipulation prevented tunnelling as originally planned, so the engineer devised an ingenious way out of the difficulty. He brought the railway to the base of the drop, and then started out to

climb up one leg of the V to the highlands above. The line could not be taken up in a single run, as the gradient would have been too heavy—those were days before the rack came into vogue—so he sawed his way up the slope. The line crawled upwards along a winding incline at 1 in 42 from one end of the ravine to the other. Here there was a dead end, but another gallery was hewn out of the cliff on a similar incline, only in the reverse direction to another dead end, from which a third ascending grade carried the line to the top. It was exasperatingly slow and perilous work, cutting the three ascending shelves in the mountain-side, following its windings, and erecting massive masonry viaducts over the deep rifts. In ascending the mountain-side the engine hauled the train along the bottom gallery to the dead end; then it pushed it up the succeeding step to the second dead end, where the engine, being once more to the front, hauled its load to the top, and thence on to Bathurst.

THE ZIGZAG THROUGH THE BLUE MOUNTAINS, NEW SOUTH WALES.

The elimination of this extraordinary piece of railway engineering cost about £350,000 for a distance of seven miles.

The "Zigzag," as this striking example of engineering skill was called, became one of the sights of the country, but in course of time it played havoc with economical operation. Train weights became limited as well as speeds, and this threatened a congestion of traffic. Accordingly, the issue of eliminating the Zigzag arose. It was certain to be a costly proceeding. This fact was realised fully, but overhaul in railway work is always costly.

A new scheme was prepared, and, like the original project, it was debated, revised, restored, pigeon-holed, and revived in turn. At last, in response to pressure, it was attacked boldly, and a new location was made so as to avoid the Zigzag altogether. It was a wide, circuitous deviation, entailing deep cuttings and heavy tunnelling through projecting spurs and humps protruding from the main range. The tunnels, ten in number, for the most part are short; but some of the

cuttings are of immense depth, one having walls of earth sloping upwards for 132 feet. Grades were eased, and the curves opened, the banks rising 1 in 90 instead of 1 in 42, while the curves are of 924 feet instead of 528 feet radius. By the time the task was consummated about £350,000 had been expended to bring this short length of seven miles into conformity with modern railway ideas.

This re-modelling process is being pushed forward more feverishly than ever in all parts of the world. Every country is having to pay a heavy penalty for the mistakes of the pioneers. Every minute which can be saved is vital to the operation of a railway in these days of bitter competition. "Spending millions to save minutes" may have become a trite expression, but it is the governing watchword of every railway between the two Poles.

CUTTING OUT THE ZIGZAG, NEW SOUTH WALES.
A heavy cutting: showing clearing through the bush for right-of-way

THE FADES VIADUCT ACROSS THE SIOULE RIVER, PUY-DE-DÔME, FRANCE.

Building the World's Loftiest Bridge

THE CENTRAL SPAN OF THE FADES VIADUCT IS 20 FEET HIGHER THAN THE TOPMOST POINT OF THE FORTH BRIDGE

WHILE it is always somewhat hazardous to award the palm of distinction to any particular undertaking in the field of engineering, it is probable that pride of place in bridge building, so far as height combined with length is concerned, is occupied by the Fades Viaduct, which spans the wide, deep, verdant gorge through which flows the Sioule River, below St. Eloy, in the province of Puy-de-Dôme, France. It is undoubtedly a meritorious work, rivalling even the masterpiece of Monsieur G. Eiffel at Garabit, not far distant. Although not quite so long as the last-named structure, the level of the railway metals is over 30 feet higher. If the Fades Viaduct were planted across the Firth of Forth, the towers of Sir Benjamin Baker's huge cantilever structure might be placed comfortably beneath its central span, and yet leave 20 feet head room.

The urgency of this undertaking had been maintained for many years in order to complete the Tulle-Clermont and Montluçon-Gannat railway. But the Sioule River offered an insurmountable obstacle. The ravine is a huge deep V in the rugged centre of France, the banks sloping down at an angle of some 45 degrees to the river at the bottom, while the distance across the gap at the top exceeds $\frac{1}{4}$ mile. Investigations proved that the only means of negotiating this interruption was by connecting the upper points of the V, it being impossible to carry the line down the valley slopes to cross at a lower level.

COMMENCING THE STEELWORK ON ONE OF THE SHORE SPANS: SHOWING THE WIRE-NETTING ENCLOSED TRAVELLER.

A wide variety of competitive designs for a bridge were prepared and submitted to the authorities. After careful investigation the proposal of M. Draux, the Government engineer, found favour in Ministerial eyes. The successful engineer when submitting his ideas was careful to emphasise that the difficulties of erection would be abnormal, and that new, untried methods would have to be called into service, the success of which, from lack of experience under similar conditions, was uncertain. The issue became complicated, because during the examination of the various designs other unexpected problems came to light, so that the whole question had to be threshed out anew.

Considerable delay thus arose. Repeated adjurations were made to commence the work, but the authorities refused to be hurried, in view of the magnitude of the enterprise. There must be no possibility of failure; no cessation of work when once started, through the "unexpected" suddenly revealing itself; and, above all, absolute safety must be assured. Every contingency that might crop up was considered and due provision made therefor.

When official approval was extended at last, the designs provided for a bridge with a total length of 1,526 feet divided into four spans. The outstanding feature was the main span above the waterway and its massive masonry piers.

The first move was the preparation of

the masonry work, and troubles were experienced almost at the beginning.

A False Start.

On the St. Eloy side of the valley the contractor carried his excavations down to a depth of 23 feet to secure foundations for the abutment, but failed to discover anything better than badly cracked rock. Instead of driving more deeply in the hope of finding firmer ground, he started to lay his foundations upon this broken surface, endeavouring to secure homogeneity by introducing a system of interlocked steel bars. The masonry had been carried up to a height of 98 feet when labour was stopped suddenly. The whole mass was sliding downwards into the valley! This was quite an unexpected development. The engineers hurriedly made a number of borings to discover the cause of this mishap, and found that the subsoil was absolutely unsafe. Without further ado the whole of the masonry was demolished and its use abandoned in favour of a short steel span.

At this juncture the masonry contractor died, and the whole undertaking was

Preliminary Work.

suddenly thrust upon the famous Société Française de Constructions Mécaniques—formerly the Cail Company—of Denain, who had been awarded the contract for the steelwork only. Upon arrival at the site the first question was the establishment of temporary communication between the opposite sides of the valley, to facilitate the movement of the constructional material and men. A small incline railway was laid down each slope and connected at the bottom by means of a wooden bridge across the river. In this way it was possible to pass from the brink of one bank to that of the other in a few seconds, thereby avoiding the tedious toil along the highway which zigzags down the valley sides. An electric generating station was established with the dynamos driven by motors fed with producer gas, since electric energy was used throughout for driving sand-mills, mortar-mixers, lifting gear, and a hundred and one other operations.

The most important and difficult part of the undertaking was in connection with the main span, 472½ feet in length, which lies immediately above the River Sioule. When one stands on the rails in the centre of this span, the water flows 434 ft. 8½ in. below one's feet. This central mass of steel is supported at each end upon a huge masonry pier. These piers are of rectangular shape, with the longest sides parallel with the river. They rise in scarcely perceptible curves to the top, which gives them a graceful, substantial appearance.

A Span of 472½ feet at a Height of 434 feet.

The erection of the piers proved somewhat costly owing to their dimensions. Each rests upon a solid massive plinth carried deeply down to the solid rock. At the base they measure 72 feet in length by 38 feet wide, and rise to a height of 302 ft. 4 in. above the foundations, tapering gradually to 36 feet by 18 feet at the top, where they are finished tastefully with a decorative stone coping, projecting 3 feet from the face of the towers.

How the Piers were Constructed.

Construction was carried out from the inside, thereby dispensing with elaborate external scaffolding. A shaft extends from top to ground level, and this vertical passage was used by workmen and also for the conveyance of the building material. The latter upon reaching the building level was handled by a small derrick which lowered it where it was required. Granite was used exclusively, although it had to be brought from a quarry some 10 miles away, while it was subjected to elaborate tests to ensure the stipulated quality. Small cubes of the stone, measuring 2 inches, representing the material for the inner lining, were submitted to crushing, and were found to resist a pressure of 7,865 pounds per square inch, while the granite selected for facing and

the decorative coping resisted a pressure of 8,840 pounds per square inch.

Piers Cost £52,000.

Owing to the diminishing sectional area of the towers as they rose upward, the space upon which the masons toiled grew more cramped every day. When the last course of stones was set in position the labourers were almost on a level with the tableland on either hand. Then a heavy cradle was rigged up to encircle each pier, and swung from the corners of the tower tops. This was lowered, with a small gang on board, who pointed and applied other finishing touches to the stonework facing, being hauled up and down from their working level on the swinging platform, which was caged in to protect the men from falling. By the time these two lofty piers were completed £52,000 had been expended, while the total cost of all the earthwork and masonry for the structure was £98,000.

Danger from High Winds.

As the towers approached completion preparations for setting the steelwork were advanced. The shore span of 380 feet springing from the Pauniat side was taken in hand first, in 1904. When it was decided to erect the lofty masonry piers, serious objections were raised in certain quarters that high winds would set up heavy oscillation—that they would sway to and fro in the same manner as tall factory chimneys and other similar structures respond to the pressure of the winds. The engineers, however, who had studied the wind velocities minutely, replied that they had so designed their work as to balance any such stresses that could be brought to bear upon it, and with a good margin to spare. Moreover, they maintained, once the steelwork was in position, that the whole fabric would be braced together and be rendered as rigid and solid as a rock.

The Steelwork.

The first half of the shore section was built upon a heavy timber falsework. When the steel reached the outer edge of this timbering it was continued over the intermediate gap of 190 feet to the top of the first main pier. To counterbalance the increasing weight of this overhanging section a huge counterweight of steel rails was placed upon the part of the span already completed at the shore end. The steelwork, comprising a rectangular structure measuring $22\frac{3}{4}$ feet wide by 40 feet in height, built up of two main side-lattice-work trusses, was erected upon lines evolved by M. Cartier, one of the engineers to the Cail Company. There was a large cage, which slipped over the end of the truss. This was fitted with rollers, which ran along the top girders, so that the cage could be pushed forward as the steelwork crept outwards. In order to extend complete protection to the workmen this traveller was enclosed in network to the top of the sides, while the floor was solid. Consequently, if a workman missed his footing he was saved from certain death. Similarly the loss of tools was obviated, as they could be recovered easily.

The Electric Crane.

On the top side of this cage a small overhead travelling electric-driven crane was mounted. As it was able to move over the full length and width of the metallic work, this appliance commanded the whole working area, so that the heavy pieces of steel were lowered into position easily, while the cumbrous tools by which the sections were riveted up were similarly moved from point to point as desired. After the Pauniat shore span was completed to the first pier, the timber falsework was taken down, transferred by the incline railways to the St. Eloy bank, where the shore span, of identical length on that side, was set in position in a similar manner.

The completion of these respective shore spans left the long gap, $472\frac{1}{2}$ feet in width, over the river to be bridged. This was the most difficult and hazardous part of the

THE FIRST COMPLETED SPAN OF THE FADES VIADUCT.
The view shows the engineers' inclined railway down the valley side.

THE TIMBER FALSEWORK FOR ERECTING ONE-HALF OF A SHORE SPAN.

whole undertaking. No timber falsework was possible here. Instead, the section had to be built on the overhang method. An erection cage, which with its overhead equipment weighed about 80 tons, advanced boldly into mid-air from each tower to meet immediately above the centre of the Sioule River. Care was observed to maintain the same rate of advance from each side, so that the two cages might reach the centre simultaneously. Erection was accomplished fairly quickly, the steelwork creeping forward through the air at the rate of $4\frac{1}{4}$ feet per day from each arm, making a total advance of $8\frac{1}{2}$ feet per day. When the centre of the gap was almost reached a small footbridge was thrown from arm to arm, affording communication between the advancing trusses, and, when at last the two cages met, they were bolted together, and preparations made to join the two sections of the span together.

The connection of two such immense steel limbs in mid-air is a delicate operation demanding extreme care; the two extremities had to be brought dead in line, both horizontally and vertically. The weight of the overhanging sections had caused the two extremities to sag about 13 inches. This defect had first to be corrected, and any possible lateral deviation provided for. This was accomplished by the aid of hydraulic jacks, which were set beneath the span on the main piers, and also beneath the ends of the steelwork on the bank abutments. As the weight of steel to be moved represented about 1,200 tons, four jacks, each capable of lifting 300 tons, were placed on the piers in such a manner that the entire arms of steel could be moved sideways as well as up and down. By lifting the whole mass of steel on the main piers and lowering the jacks on the abutments, the end of each limb of steel was canted

upwards until the deflected extremities were dead in line.

In such work as this the temperature of the atmosphere plays a very vital part in the final operation. The expansion and contraction of such a long mass of steelwork under the fluctuations in the heat of the sun's rays is appreciable. As the Fades Viaduct lies across the gorge in a north by south direction the sun plays only on one side of the structure at a time, so that expansion is unequal. This fact demanded skilful treatment. The closing operation took place on May 17th, 1909. The east side was closed when the sun was shining brightly. When the girders forming the chord were lowered into position it was found that the 1-inch rivet holes therein came flush with the relative holes in the fixed part of the bridge. Accordingly bolts were slipped in and the breach on that side closed speedily. On the west side, as it was in the shade at the time, the holes in the closing girder and the ends of the arms were out by $\frac{5}{16}$ inch. Consequently a temporary closure was made on this side by driving home $\frac{9}{16}$-inch bolts. At a later hour, when, under the influence of the sun's rays the west side of the bridge expanded, the temporary bolts were withdrawn, as the holes came accurately together to permit the 1-inch rivets to be driven home. The jacks on the main piers afterwards were lowered, so that the steelwork came to rest in its normal position upon the expansion rollers.

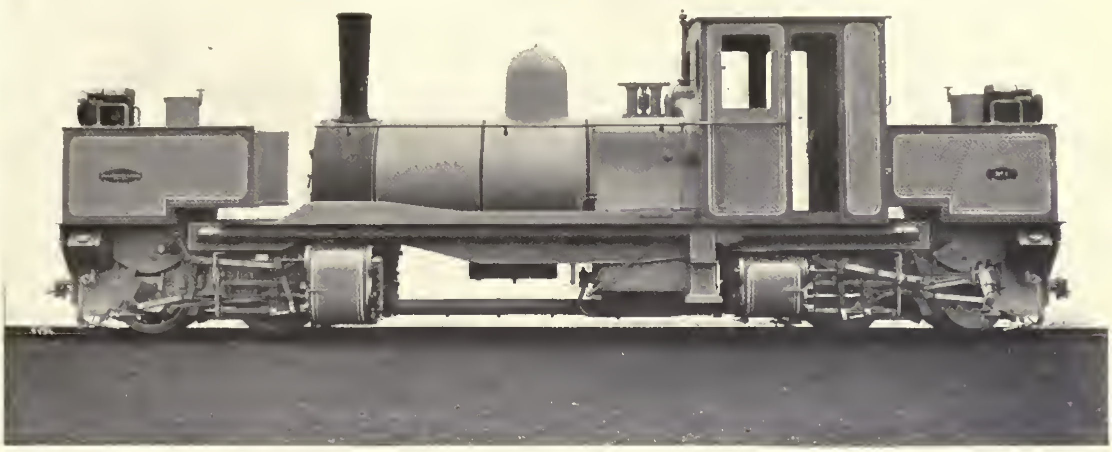
Owing to the elaborate precautions adopted, only one life was lost over this great work, and this occurred during painting operations. The bridge carries a single

CRAWLING FOOT BY FOOT TOWARDS THE FIRST PIER.
Showing timber falsework for half the distance, and counterweight at shore end to counterbalance weight of overhanging section.

railway track of standard gauge on the top deck. Special arrangements have been introduced to prevent a train, in the event of derailment, plunging over the side into the depths of the valley. The bridge has been designed so as to be able to withstand any load that might be brought to bear upon it even under the most disadvantageous circumstances. On the upper deck there is a narrow footway, level with the metals, to facilitate the inspection of the permanent way, while a footbridge, 3 feet wide, is fitted to the bottom girders for the purposes of inspecting, repairing, and painting the bridge.

The Fades Viaduct is one of the most impressive works of its kind in the world, and commands attention on account of its great height. There can be no question that it serves as an imposing record of the skill of the French bridge builders. It was a highly responsible undertaking, and some eight years were occupied in its fulfilment. After being tested it was taken over by the Paris-Orleans Railway Company in September, 1909.

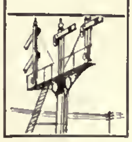
GENERAL VIEW OF THE SIOULE RIVER VALLEY AND THE VIADUCT WORKS SHOWING THE TWO CHIMNEY-LIKE PIERS.



THE "GARRATT" PATENT LOCOMOTIVE, USED ON THE TASMANIAN GOVERNMENT RAILWAYS—NORTH-EAST DUNDAS SECTION.

A New and Novel Articulated Locomotive

AN INGENIOUSLY CONSTRUCTED ENGINE WHICH MAY MARK A NEW ERA IN LOCOMOTIVE DESIGN

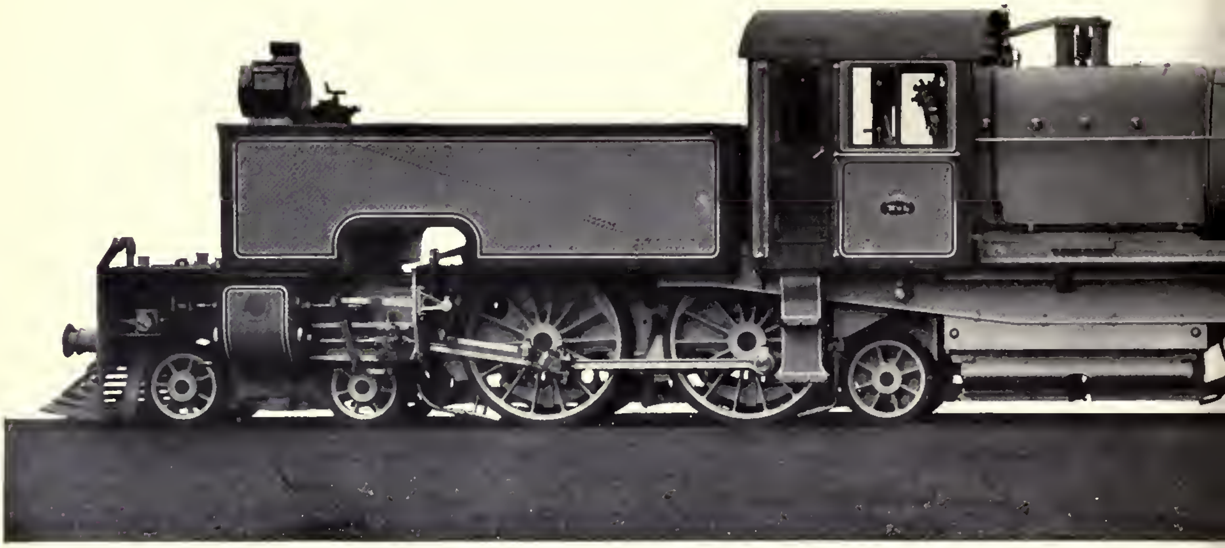


DURING the past few years the increasing demands for greater power to haul heavier and longer trains has been responsible for the display of striking ingenuity in connection with locomotive design.

Recently the attention of engineers and others concerned with the economical operation of the great railways of the world has been attracted to quite a new and novel type of steam railway engine, which has been evolved by a British inventor, Mr. H. W. Garratt, M.I.Mech.E., and the question has been discussed as to whether it does not indicate a new era in locomotive design. Although it belongs essentially to the articulated class, it has one great advantage over its prototypes—it it more flexible—and appears to meet very completely all the varying and severe requirements of the average railway, from which stretches of heavy grades and sharp curves generally are inseparable.

It is conceded generally that inventors have very little scope for further development within the recognised limits of locomotive construction, unless resort is made to the introduction of complications which are apt to counteract any benefits that may arise from the incorporation of the new feature. The boiler and the driving

wheels are two vital factors, and there is a limit to their respective diameters. The boiler has to be disposed above the wheels, and the dimensions of the latter influence the former to a very appreciable degree, because the over-all height of the engine is limited by tunnels and bridges. If the size of the wheels is augmented, their axles must be brought to a higher elevation above the track, and accordingly the diameter of the boiler must be affected.



EIGHT-CYLINDERED GARRATT

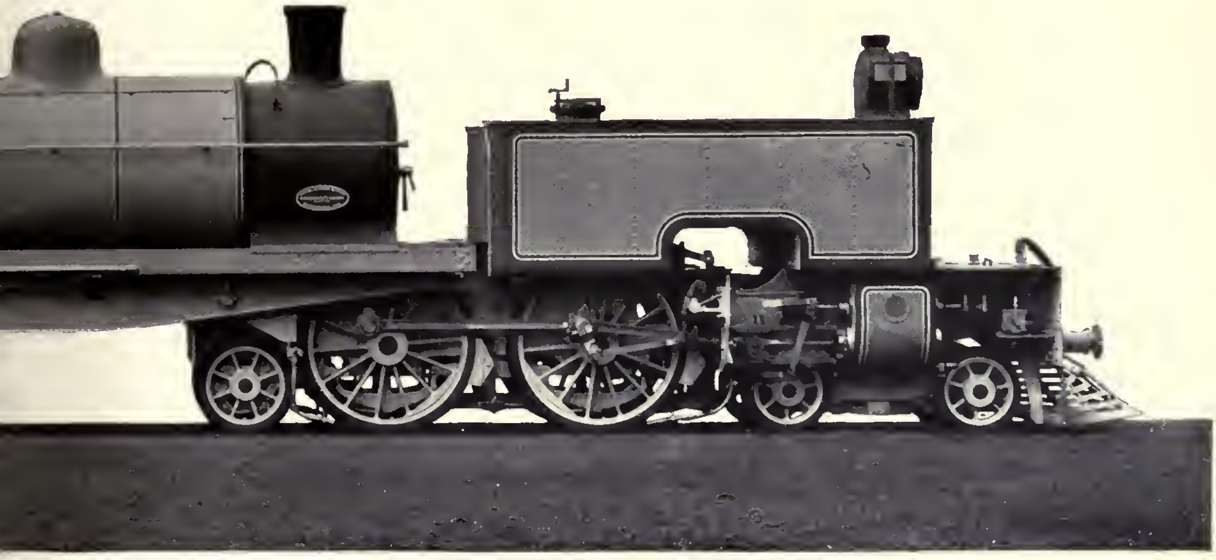
The questions of weight distribution and a large grate area of proper proportions also influence the situation very materially. Locomotive engineers have surmounted these various handicaps by lengthening the boiler and increasing the number of driving wheels, but this has given birth to another objection. It is useless to extend the length of the boiler without enlarging the grate area of the fire-box to secure the maximum steaming capacity and complete economical combustion of fuel. Lengthening the boiler in turn precipitates the possibility of eliminating all the advantages incidental to the articulated system. The bogies, which should have free and easy movement, are rendered stiff and unnatural, so that they cannot accommodate themselves readily to the curvature of the track; flexibility, which is so keenly demanded, is imperilled gravely, if not destroyed.

In these circumstances the problem which Mr. Garratt sought to solve was necessarily of a complex and searching character. In order to achieve any measure of commercial success it was necessary to depart from conventional lines. In this quest, however, he has succeeded, and his efforts culminated in the production of a design which is distinctly novel, ingenious, effective and economical in working. When he had completed his ideas he submitted them to one of the foremost British locomotive building organisations, Messrs. Beyer, Peacock and Company, Limited, of Gorton Foundry, Manchester. They readily appreciated the outstanding features of the new system, acquired the patents, and undertook to exploit the invention. Several months were expended upon the perfection of the details of the designer's handiwork. The first opportunity to ascertain the possibilities of the system came when the

chief engineer of the Tasmanian Government railways suggested that small engines of this class should be given a practical test upon the State system of the island.

This was about as severe a test as could be conceived for a new idea. The locomotives were required for working upon the North East Dundas section of the State system, where the gauge is 2 feet, with grades running up to 1 in 25, and with curves of 99 feet radius. Rigid stipulations were laid down to which the engine had to conform, so that it cannot be said that the inventor was given the opportunity to demonstrate his ideas under the (to him) most favourable conditions. Two locomotives were built and shipped to Tasmania in 1909, where they have been running continuously ever since.

The salient feature wherein the Garratt locomotive differs from its contemporaries is that the boiler is a distinct unit, and is not mounted above the driving wheels in the usual way. Fundamentally it comprises three sections: the boiler with its fire-box, and two end bogies, each of which is a driving unit, so that it may be described as a boiler and two complete motor bogies, one placed at each end, as the latter carry the cylinders, pistons, and driving gear. The boiler, including fire-box and cab, mounted upon its frame is carried between the two bogie trucks, so that the wheels are not brought beneath the boiler and fire-box. The advantage is obvious. As there are no restrictions arising from the presence of wheel axles,



PASSENGER LOCOMOTIVE

the diameter of the boiler may be increased very appreciably, while there is no fear of cramping the fire-grate. In fact, the whole may be placed so low as to leave only the minimum clearance between the rails and the bottom of the fire-box. This feature exercises its advantages in several ways. In the first place the centre of gravity is kept low, ensuring steadiness and safety in running at the highest speeds; the driver has a clearer view of the road ahead and behind, owing to the large-sized cab windows that can be fitted; while, if necessary, the boiler diameter can be enlarged to about 20 per cent. more than is possible under present conditions, even if a Garratt type comparable with the huge Mallet engines is evolved.

The two end bogies, in addition to carrying the driving mechanism, are also utilised for the bunkering of the coal and water, so that a tender in the usual sense of the word is rendered unnecessary. The weight thus imposed not only increases the adhesion of the wheels, but when the locomotive is running at high speed, they effectively assist to prevent oscillation of the bogies, so that the wear and tear upon the flanges of the wheels, and also the rails, is reduced to a minimum. The capacity of the tanks may be varied according to requirements, this factor being governed entirely by the number of wheels to the bogie and the axle-loads permitted.

End Units Used for Coal and Water.

In the case of simple expansion working, the steam from the boiler is taken from the dome by means of two regulators with piping, one of which extends to the smoke-box end of the central unit, and thence to the front bogie through a flexible joint; the other runs to the fire-box end, and in a similar manner to the rear bogie, a **Y** pipe in each instance delivering the steam to the cylinders on either side.

Advantages of the Type.

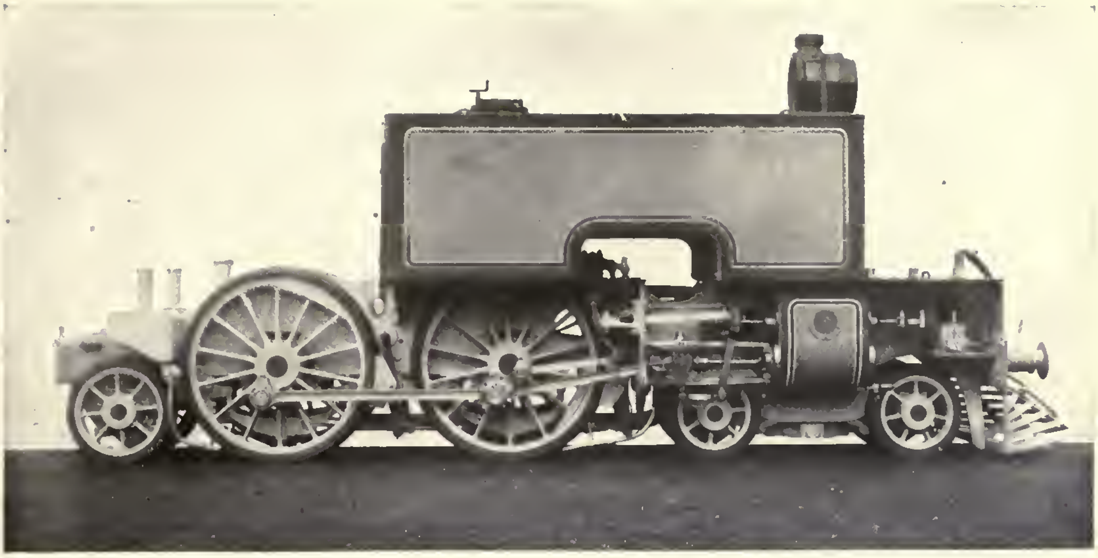
By dividing the locomotive into three parts in this manner the full effects of articulation are obtained. Owing to the rigid section, that of the boiler and its frame, being kept as short as possible, and the two bogies having free play, the sharpest curves and inequalities in the track may be negotiated with extreme ease, and the flexibility is such that the whole engine conforms with natural freedom to the curve. In rounding a curve, the rigid central section forms a true chord of the arc, while the sharper the curve the more the centre of gravity is brought inwards, so that exceptional stability is secured. The extreme flexibility of this type of engine is demonstrated most convincingly, possibly, on sharp reverse curves, which may be rounded at high speed with far greater safety than is possible with the ordinary locomotive, there being an entire absence of stiffness or grinding of the flanges against the rails. There is none of that climbing tendency of the engine which often is experienced under such conditions, and which has been responsible for many derailments. Another point which cannot fail to be observed is that there is no overhang of the boiler frame when rounding a curve, as the articulating centres are fixed at the extreme ends of this frame. This contrasts very vividly with the overhang of the boiler and frame upon the general type of semi-rigid articulated locomotive, which is now so much in vogue.

The Question of Distribution of Weight.

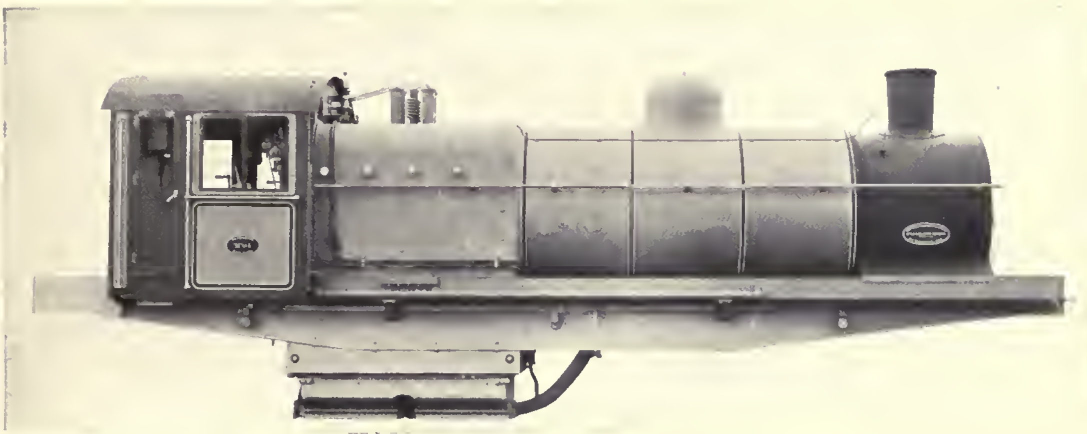
It might be thought that difficulty would arise in distributing the loads uniformly over the axles, especially as the weight of the fuel and water is fluctuating constantly; but with efficient designing this is not so. The combined weight of the fuel and water represent such a small proportion of the total weight of the bogies that even if the whole of these commodities were consumed—in actual running it is very improbable that their weight would fall below 20 per cent. of the full load—there is still ample weight upon the wheels; the variation in the loads upon the axles certainly would not be more than in the ordinary type of tank engine which is in daily use.

Tasmanian Experiments.

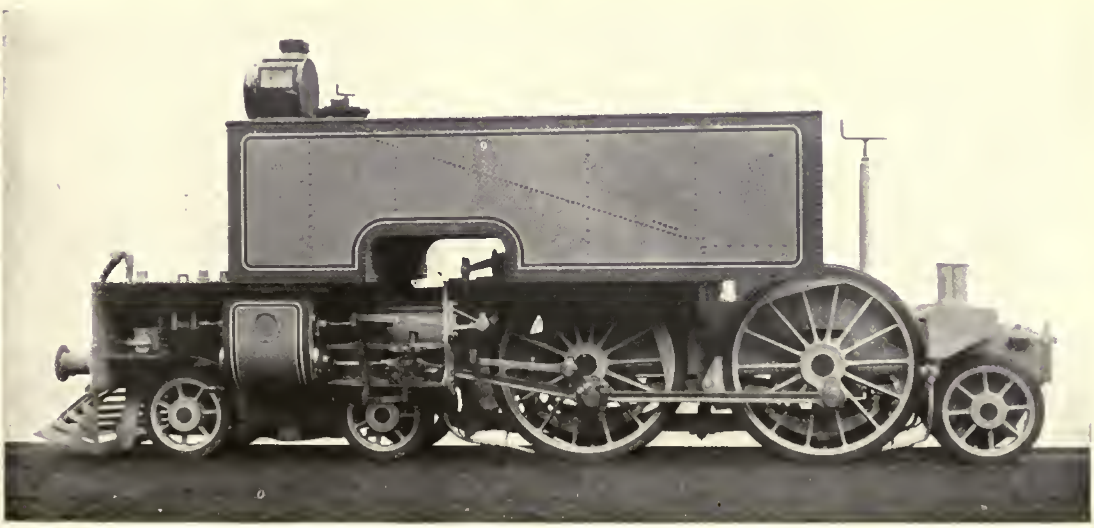
In the first engines of this type, built for Tasmania, there is a small bogie at either end, fitted with two coupled axles; compounding was stipulated, although it is not essential to the Garratt system, and its incorporation involved somewhat heavy and unavoidable complications. The high-pressure cylinders are mounted on the trailing, and the low-pressure cylinders upon the leading, bogie. In this instance the steam is led from the dome to the rear truck, and distributed by a **Y** pipe to the cylinders on either side. The exhaust steam is received



Front Engine Unit.

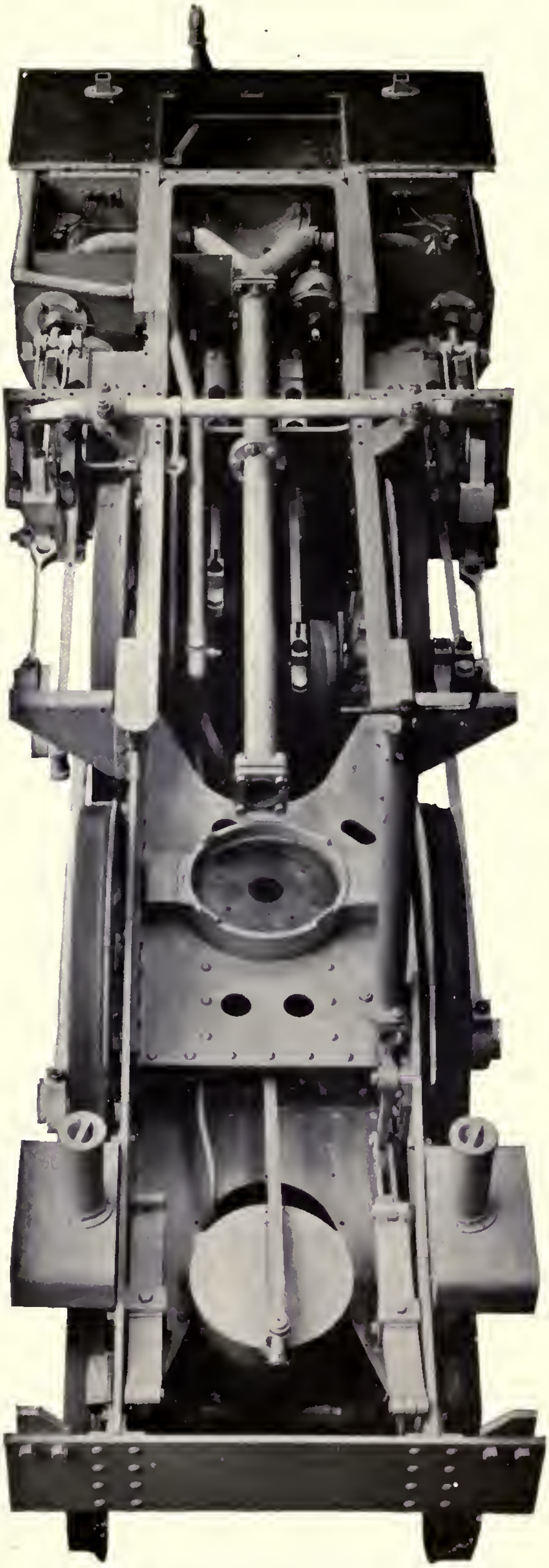


Boiler and Frame.



Rear Engine Unit.

UNITS OF THE EIGHT-CYLINDERED GARRATT LOCOMOTIVE.



LOOKING DOWN ON AN ENGINE UNIT OF A GARRATT LOCOMOTIVE.

through a second Y pipe and carried to a flexible coupling or ball-joint, then under the frame of the boiler to the front bogie, where it is distributed by a similarly bifurcated pipe to the low-pressure cylinders. The exhaust from the latter is taken back by another Y pipe and ball-joint coupling to the chimney, to be discharged into the air. For simple expansion working the cab is fitted with devices to intercept the return of the exhaust steam from the high-pressure cylinders, while live steam is admitted direct into the cylinders of the leading bogie. The high-pressure cylinders have a diameter of 11 inches, while the low-pressure cylinders have a diameter of 17 inches, with a common stroke of 16 inches. The boiler barrel is 7 feet in length by 3 ft. $11\frac{1}{8}$ in. diameter outside, and has 170 tubes of $1\frac{3}{4}$ inches external diameter. The over-all length of the locomotive is 33 ft. $10\frac{1}{2}$ in. by 7 feet wide, and the total weight in working order is 33 tons $10\frac{3}{4}$ cwt.

When the Tasmanian engines appeared they aroused considerable interest, but were regarded in many railway quarters as a novelty, comparable with the Fontaine and other unusual designs which have appeared from time to time. But the experience gained on the Tasmanian railways tends to indicate that the engines are eminently adapted to peculiar conditions. While inquiries concerning the adaptability of the idea to other countries commenced to roll in, the system received its complete vindication when the Tasmanian Government, which first had submitted the idea to practical trial, ordered larger and more powerful types for their main lines. Here again a variety of difficult and rigid requirements had to be fulfilled, for which Mr. W. R. Deeble, the chief mechanical engineer to the Tasmanian Government, concluded that the Garratt system offered the only solution.

In Tasmania the railway situation has developed, as it has in other countries.

Increased weights had to be handled by the engines. The adoption of corridor coaches in the express passenger service doubled the weight of the train to be handled by the existing locomotives, and, in combination with high speed, the ordinary type of engine was ruled out of court upon the 3 feet 6 inch gauge with grades of 1 in 40 and curves of 330 feet radius. The axle-loads and length of the fixed wheel base were restricted by the physical characteristics of the road, while speed imposed special conditions concerning the size and distribution of the wheels, as well as the balancing of the reciprocating forces, so as to prevent side movement.

The situation has been met completely by a Garratt simple locomotive, having two groups of four-coupled wheels, with four-cylinder balanced engines, each having an inner pair of carrying-wheels and an outer four-wheeled bogie. Virtually it is an Atlantic type of engine adapted to the Garratt system, with coupled wheels of 5 feet diameter. The weight upon the driving axles varies between 11½ to 12 tons per axle, with a rigid wheel base of 6 feet, and capable of attaining speeds up to 50 miles per hour on the straight, and 30 miles per hour round reverse curves of 330 feet radius. This is probably the most powerful articulated locomotive yet built for passenger service upon a 3½ feet gauge.

A GARRATT LOCOMOTIVE FOR THE DARJEELING-HIMALAYAN RAILWAY, ON A REVERSE CURVE OF 60 FEET RADIUS.

So far as the goods locomotives are concerned, the same governing factors, except high speed and axle-load, which was limited to 9½ tons, had to be taken into consideration. For this work a Garratt simple goods locomotive of the 2–6–2, 2–6–2 class was adopted, there being two groups of six coupled wheels, with two cylinder engines, each having an inner pair of carrying wheels provided with side play, and an outer two-wheeled radial bogie, the coupled wheels being 3 feet 6 inches in diameter, with a rigid wheel base of 8 feet. This arrangement of the wheels affords the maximum-powered engine on the specified axle-load.

The absence of side tanks and of wheels below the boiler—the characteristic features of the Garratt locomotive—has facilitated the provision of a large boiler of simple and well-proportioned design, with a wide and

deep fire-box of the Belpaire pattern. The one design of boiler in this instance is common to both passenger and goods engines, and provision is made for using oil fuel if desired.

The Tractive Effort.

In the Garratt locomotive the power or tractive effort is governed solely by the permissible load per axle, and the number of coupled axles, since in this type the boiler can be made so large as to be capable of supplying sufficient steam for cylinders of such proportions as may be required to make full use of the adhesive weight. For instance, for standard gauge working, a Garratt engine, with two six-wheel coupled bogies—0–6–0, 0–6–0 type—with a load distribution of 18 tons per axle, has a tractive effort of 50,000 lb. Such an engine on the level could haul 3,000 tons, or 850 tons up a grade of 1 in 50, at a speed of 10 miles per hour. The total weight of the locomotive—no tender—would be about 108 tons, and the total length about 62 feet. Similarly, another engine, with two eight-wheel coupled bogies—0–8–0, 0–8–0 type—having a load of 20 tons per axle, has a tractive effort of 72,000 lb. This would be sufficient to pull 4,500 tons on the level, or 1,200 tons up a bank of 1 in 50, at 10 miles per hour. In this case, while the engine would weigh 160 tons complete, and have an over-all length of about 67 feet, the longest rigid portion would only be some 30 feet.

Up to the present engines of this design have not been adopted for working upon standard gauge railways, but owing to the success of the engine upon narrower gauges, combined with its great possibilities, the day doubtless is approaching when it will be taken up for such work. It may not be seen for some time in this country, since the problem of the railway locomotive is not so acute as in the United States, Canada, and India, where heavy banks, sharp curves, and mammoth train loads are more common.

Advantages of the System.

Railway operators cannot fail to appreciate other advantages which the system offers, and which tend towards highly economical working. The design and arrangement conduce to easy riding, so that the track is given a longer lease of life, while the engine itself is spared those severe racking strains and stresses inseparable from the conventional articulated locomotive. It forms a perfect double-ender, and can be driven in either direction. This facility affects another question. Turning for every trip is dispensed with, so that turntables are not required. This in itself represents a distinct advantage, seeing that the monster locomotives used for handling heavy loads demand turntables ranging up to 90 and 100 feet in length, with massive foundations. If the development of the Mallet engine offers any criterion of the limits to which locomotive dimensions and weight may be carried, it is not impossible to assume that the Garratt engine will undergo development to the same degree, giving greater power with smaller dimensions. This possibility has been anticipated, since, if the boiler is brought up to the height of the largest Mallets, the outlook from the cab will be reduced. This disability will be met by placing another cab forward of the smoke-stack, to be used for forward running, the existing cab being employed for driving in the reverse direction.

The ease with which overhaul and cleaning operations can be carried out must not be overlooked. Owing to the fire-box being free from the presence of wheels and tanks in close proximity, the wash-out plugs, etc., are quite accessible, as is also the ashpan for the rapid clearing out of ashes. By lifting the boiler unit and making a few disconnections, the two bogies can be drawn quite clear, the three units being thus easily accessible for overhauling.

THE WETTERHORN AERIAL RAILWAY

Aerial Mountain Railways

THE METHOD OF ALPINE VIEWING WHICH IS SAFE, LUXURIOUS, RAPID, AND POPULAR

WHILE the cog-wheel railway for the ascent of steep mountains has been brought to a high standard of development, and has been adopted widely during the past forty years, it is somewhat expensive, both as regards first cost and maintenance. The result is that many of the grandest and steepest mountains still are able to defy railway conquest.

During the past few years, however, a new system of railway mountaineering has been perfected, and has been brought into practical operation both among the Alps and the American Rockies. This is the aerial railway, wherein the car is slung from a wheeled bogie carriage running along a steel cable stretched through the air.

This idea was introduced by a British firm many years ago. The proprietors of a sugar-mill in Hong Kong acquired a site upon the elevated plateau overlooking the coast for the housing of their European staff, the level of the works being somewhat unhealthy. In order to expedite and facilitate movement between the two points, the London firm of Bullivant, which had previously completed several aerial railways for the transport of merchandise, was requested to instal a similar line between the mill and the residential centre. It was completed at a cost of some £5,000, and met the situation very completely.

The line is carried upon lattice steel

A CAR ON THE WETTERHORN AERIAL RAILWAY.
The two cables forming the track are mounted one above the other.

THE UPPER STATION ON THE WETTERHORN AERIAL RAILWAY.
Over 6,000 feet above sea level.

towers, the track being a single steel rope, along which runs a two-wheeled truck, from which is suspended the travelling carriage, resembling a light double deck seat with the passengers sitting back to back. An endless rope attached to the car hauls it up and down at a maximum speed of 8 miles per hour.

Since this pioneer line was built aerial railway travelling has made giant strides. The Hong Kong undertaking is a private concern, so when it came to catering for the public upon similar lines, many questions had to be taken into consideration which did not affect the first-named enterprise. The first public railway of this character, designed essentially for public service, was that up the Wetterhorn, in the Bernese Oberland. The idea was elaborated by Herr Feldmann, who supervised the construction of the Barmen-Elberfeld suspension railway, described in another chapter.

This engineer evolved an entirely new system, so far as its details were concerned, wherein unassailable security was ensured. He adopted two ropes to form a track, one being placed above the other. There are two tracks, each carrying a car, and as the latter are connected together by the hoisting rope, one ascends while the other descends, thereby securing a certain measure of counterbalancing, as is adopted on the incline railway. By disposing the two ropes, forming a single track, one above the other, and by using a four-wheeled travelling truck having two wheels on each rope, increased stability of the suspended cars —especially in high winds—was obtained.

Although this ingenious engineer did not live to see his idea carried into practical application, yet his plans were prepared so completely that they were easy to fulfil. The contract was undertaken by Messrs. Von de Roll, of the Fonderie de Berne, who have made a speciality of mountain railway engineering in all its varied branches.

The lower station is situate at an elevation of about 5,500 feet above sea level, while the upper station is 1,380 feet higher and 1,200 feet distant in a horizontal line. The gradient is thus somewhat steep. The track cables are each 1·93 inches in diameter, and are built up of 96 steel wires disposed in five layers around a central wire. The two cables forming a single track are spaced $2\frac{3}{4}$ feet apart, while 26 feet separates the two lines. Each cable weighs 7·4 lb. per foot, and is able to withstand a stress of 154 tons, so that with the estimated

maximum load per cable of 13·8 tons there is a very wide margin of safety. The cables are maintained at a constant tension by the aid of a counterweight of $18\frac{1}{2}$ tons in the lower station, and any weakening of either cable is compensated automatically. Should one cable break, the second is quite strong enough to support the car.

The travelling truck, as already mentioned, is fitted with four wheels and a guide wheel, two running on the upper side of each supporting cable, while the framing ensures the wheels securing a constant grip upon their respective surfaces, so that derailment is impossible. Each truck is coupled to two hoisting cables, 1·14 inches diameter, built up of 90 steel wires woven together in six strands. These cables will withstand a pull of 43 tons before breaking, but in service the strain is only $2\frac{1}{2}$ tons. They are connected to the travelling truck through a cross arm which brings them 5·4 feet apart. The cars are attached to the respective ends of these hoisting cables, which are passed round two winding drums driven by a 45-horse-power electric motor in the upper station.

From the wheeled truck depends the triangular framing from which the car is suspended. The carriage is about 10 feet square and 8 feet in height, with seating capacity for eight passengers and the driver. If required, however, seventeen people can be carried, there being standing space for nine persons. Each car in the empty condition weighs over 4 tons, so that when fully loaded the total weight is well over 5 tons.

The safety devices which are incorporated to ensure the security of the passengers are of a very complete character. The travelling truck carries automatically operating brakes. If a hoisting cable should snap the car is arrested immediately, the

INTERIOR OF THE DRIVING STATION, WETTERHORN AERIAL RAILWAY.
Showing the two great winding drums driven by a 45-horse-power electric motor.

brake being so powerful that it is able to bring the vehicle to a standstill, when travelling at full speed, within less than one foot. This brake can also be applied by the driver from the car; but in any event he has to climb to the railed-in roof of the car to reset it before the journey can be resumed.

The driving station also is supplied with numerous devices to the same end. If the

The Car Cannot Run Away.

electric current supply should fail, the car attain too high a speed, or the machinery reveal some defect, a magnetic brake acts on the winding gear. The engineer is supplied with indicators which reveal the speed and position of the cars on the track throughout the journey. So a car cannot run away.

Failure of the electric current from the public supply, however, does not bring the

Supplementary Electric Supply.

railway to a complete standstill. In the lower station is a secondary battery, which is kept fully charged, and this is able to run the vehicles through twenty-five journeys. Neither can the passengers become stranded on the track midway between the two stations. If the machinery breaks down completely the winding sheaves can be operated by manual effort to bring the cars in. As it is quite possible, although very remote, that a car may come to a standstill along the track owing to some defect developing in its mechanism, there is a small emergency car which can be let down the track to the stalled vehicle to take off the passengers; this little vehicle can be operated either through a small electric motor or by hand.

The cars are suspended from their carrying truck in such a way that they maintain

Car is Always Horizontal.

an even deck throughout the journey, irrespective of the inclination of the track. Thus on the uppermost section of the line, where the gradient is exceedingly severe—it is almost vertical—the feeling of being transported in a lift is conveyed, there being no impression of the steepness of the climb, except by taking stock of the surroundings.

After being submitted to the most exacting tests by the Swiss authorities, the Wetterhorn Aerial Railway was opened for public service in July, 1908. Since then it has been running continually without the slightest mishap.

Herr Josef Staffler, of Bozen, had contemplated a similar conquest of the Kohlerer mountain in the Austrian Tyrol.

The Kohlerer Railway.

This peak was provided with a primitive aerial ropeway carried on wooden supports, but under the tourist development of the country it demanded modernisation. Herr Staffler decided to adopt an aerial system as being cheaper, quicker, and more satisfactory, and forthwith discussed the question with Adolf Bleichert and Company, the well-known London and Leipzig firm, who have completed some of the most noteworthy aerial railways of the world. A scheme was evolved, and in this instance, as in Switzerland, the Austrian Government had to be satisfied very completely upon the adequacy of the public safeguards.

This aerial railway commences at Eisack, and soars up the mountain side for a distance of 5,250 feet. The dis-

Track Supported on Towers.

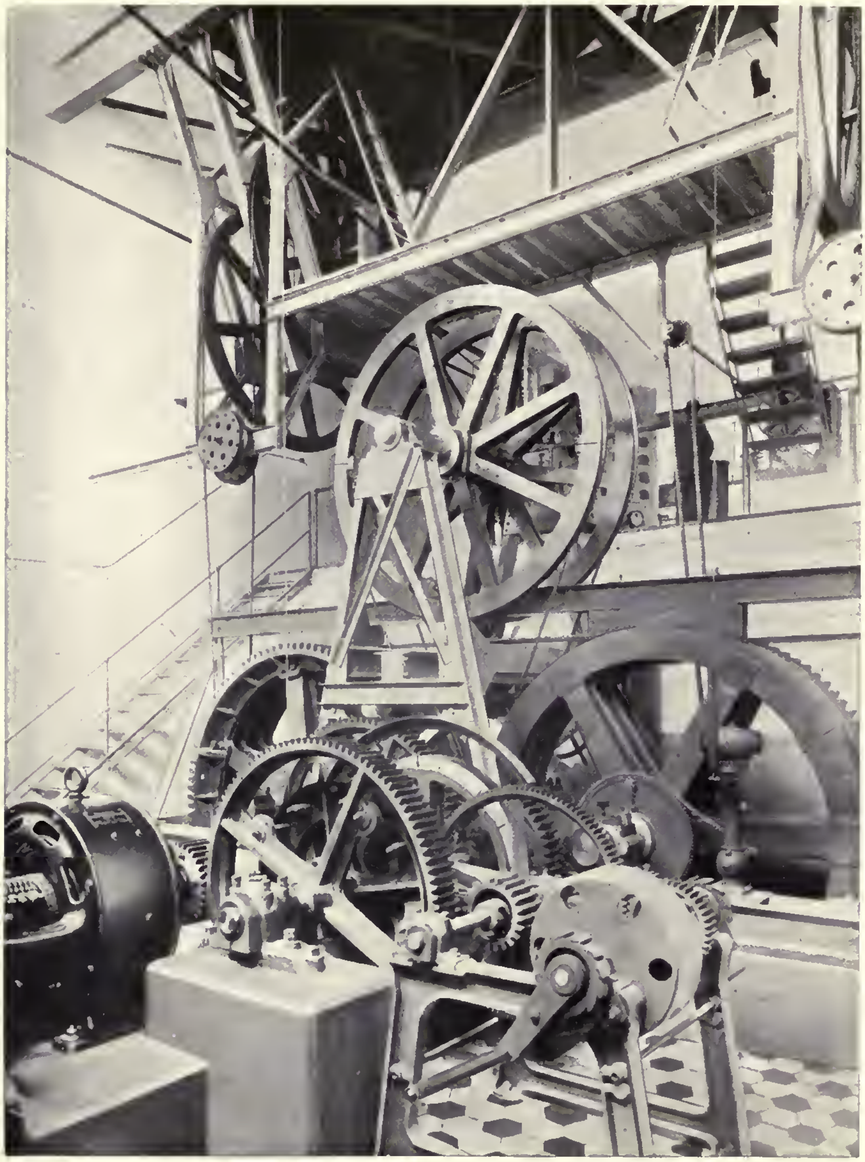
tance is not covered in a single span, as in the case of the Wetterhorn line. Twelve lattice steel towers are introduced at intervals to support the track. The latter comprises two steel ropes, each about $1\frac{25}{32}$ inches in diameter, and spaced about $19\frac{1}{2}$ inches apart. There are two tracks, one for each car, the railway being run upon the counter-balancing system. At the upper station the ropes are anchored in the mountain side, while at the lower end they are connected to massive weights, placed in a pit, in order to maintain the tension.

There are two hoisting ropes attached to

CAR ON THE KOHLERER AERIAL RAILWAY.

It maintains a horizontal position throughout the ascent of 5,250 feet.

the travelling truck, which is fitted with four wheels, two running on each rope. In this instance the two ropes are placed side by side, instead of one above the other, as in the Wetterhorn railway.



THE DRIVING GEAR OF THE KOHLERER AERIAL RAILWAY.
The machinery is electrically operated.

The towers supporting the track are of heavy construction, built on massive foundations. Their height varies from 23 to 97½ feet, according to the configuration of the mountain flank. The ropes are carried upon the supporting brackets in such a manner that no jar or oscillation is imparted to the car as its track wheels pass over. The travelling speed is about 10 feet per second, and the complete journey occupies about thirteen minutes.

The railway is electrically operated, and the starting always is carried out from the upper station after the visual and acoustic signals have been transmitted and acknowledged between the two points. Electricity is drawn from a neighbouring generating station. As the railway works upon the counterbalancing system, the additional power required is not very great. An electric motor drives a wheel to which is coupled the cable sheave or pulley, round which the cable is wound several times. Thus the drive is as direct as possible, while three braking systems serve to control the mechanism very adequately.

The car itself is suspended from the travelling truck in such a way that it maintains a horizontal position, irrespective of the gradient, and as it is fitted with large plate-glass windows, the sixteen passengers are afforded magnificent uninterrupted

views from their seats within. The roof is flat, and means of access to the overhead equipment is afforded for the driver in the event of anything going wrong or of attention to the track and truck being necessary. The suspender is a heavy piece of nickel steel, and the construction thereof, in conjunction with the wheeled truck, is such that it is impossible for the car to fall from the track.

The Brakes.

The braking arrangements are of an elaborate character to secure the unquestionable safety of the public. Should a hoisting rope break there is a powerful clip which instantly grips the track, and brings the car to a standstill, the application being automatic. This brake is so powerful that during the builder's trials, when one of the hoisting ropes was broken purposely, the vehicle only slipped back six inches before it came to a stop. Even if one of the track cables broke no alarm need be entertained, as the brake would come into operation instantaneously, and after the car had been stopped it could be restarted and driven slowly into its station along the remaining cable. This brake can be applied also by the driver from within the car in case of emergency, so that no matter what might happen it is impossible for the car to get out of control.

At the same time the stations are fitted both with automatic and hand-operating brakes to guard against various contingencies, such as the failure of the electric current, breakdown of the machinery, or of the car, etc. Then there is an accumulator battery, capable of running the railway for several hours continuously should the main supply give out. Even if this broke down while the cars were on the track, they can be wound in by hand, either with the passengers within or after an emergency car has been sent down the track to take off the travellers.

Even suppose everything went wrong, and that the cars were brought to a dead standstill, impossible of recovery for the time being, the passengers are not confronted with the prospect of dangling in mid-air for an indefinite period. The car carries an emergency apparatus in the form of a collapsible bag with a rigid bottom. This is lowered through a trap door in the floor, with the passenger standing upright within. There is no danger of a hurried descent to Mother Earth, because the lowering of this apparatus is governed by a braking gear, so that the ground is reached without any perceptible jar.

An Emergency "Exit."

Government Restrictions.

The travelling speed upon the line is restricted very rigorously by the authorities, and expedients have had to be introduced to keep within the prescribed limits. There is a speed regulator which is set to the authorised maximum. Directly the car exceeds this point the automatic brake comes into action and checks the speed. Again, the authorities forbid the operation of the railway during high winds. An anemometer is mounted upon the roof of the upper station, and this is connected to a bell signal. Directly the wind exceeds a certain velocity, to which the apparatus is set, this bell warns the mechanic to suspend the service. As a matter of fact there is no danger of the highest winds imperilling the safety of working, but the regulations of the authorities must be obeyed.

Travelling by this aerial railway is marked by the complete absence of vibration and oscillation. The cars start without any perceptible jolt and glide steadily and smoothly up and down the mountain sides. When approaching the station the speed is slackened automatically, and the vehicle is brought gently to rest. In addition to the telephone and electric lighting circuit between the station for the transmission of the audible and visual starting signals, as well as other service communications, a

VIEW OF THE TRACK OF THE KOHLERER AERIAL RAILWAY.
Showing the method of suspending the car from the track carriage, and the two cables.

special telephone wire is provided for the convenience of the driver of the car. He is in continuous communication with both stations during the journey, and can notify the engineers at both ends the moment any untoward incident develops.

Another aerial passenger railway, working upon a third system, the Ceretti-Tanfani, also has been completed in the Austrian Tyrol, to connect Lana with the summit of the Vigiljoch. While this system has been in operation upon its broad lines for the transportation of goods traffic in various parts of Europe for many years past, this is its first direct application to passenger service. In this instance, also, the Austrian Government proved most exacting in its determination to protect the public. After the line was completed the government engineers subjected it to innumerable tests of all descriptions, submitting the safety devices to the most rigorous and searching trials before they extended the requisite sanction to carry passengers.

The line is divided into two sections. The first rises 1,730 feet, while in the second section the difference in level which is overcome is 2,100 feet. Thus there are three stations. The lower terminus contains the tension gear, comprising counterweights aggregating 20 tons, for the lower line, while the uppermost station contains the electrical and other plant. The third is a half-way or change-over house. The counterbalancing system is adopted on both sections of the line, and the cars are suspended pendulum-fashion from the overhead trolley. The cable track comprises one main steel cableway along which run two two-wheeled trucks mounted in tandem in a frame.

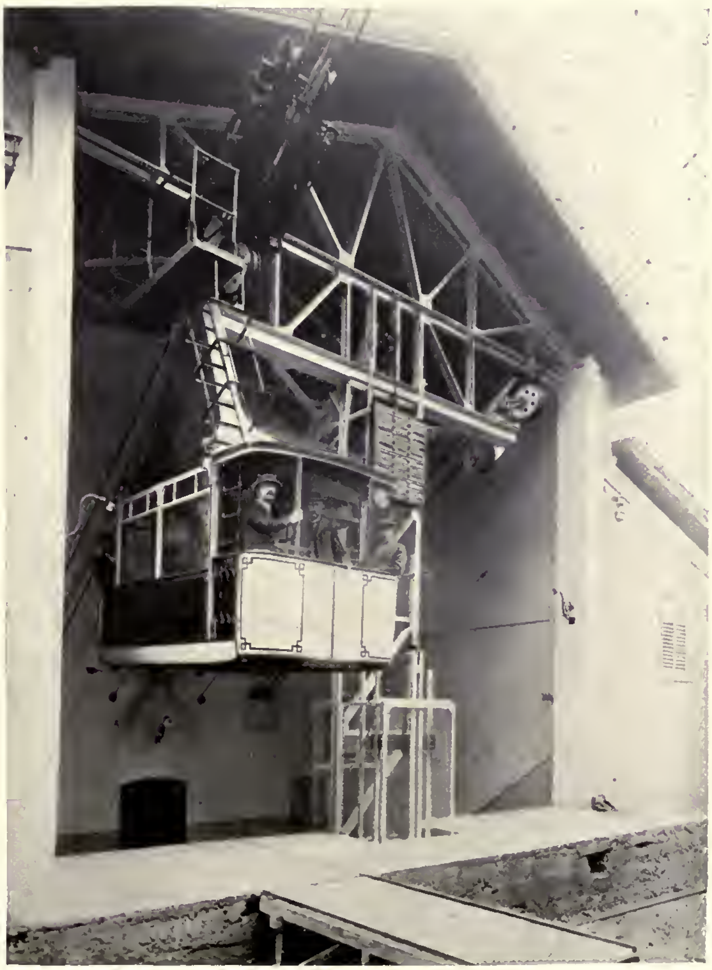
These wheels run along the top face of the cable, but underneath are guard wheels which prevent the trolley jumping the track, so that derailment is absolutely impossible. In addition to the hauling rope whereby the car is drawn to and fro, there is a brake rope on which the automatic brake of the car acts. If the exigencies of traffic demand that two cars shall travel one behind the other, each has its separate hauling rope, but the hauling rope of the leading car acts as the brake rope of the second vehicle, while the hauling rope of the following vehicle acts as the brake rope of the first car. Both these ropes are driven by drums which are operated by a common motor in the upper station, and should a braking

rope snap, the car or cars can be braked by hand. This is an ingenious arrangement, and it constitutes one of the outstanding features of the Ceretti-Tanfani patent, the value of which has been emphasised in connection with the official inspection of this railway.

It might be anticipated that, when the automatic brake was applied suddenly by the failure of the hauling rope, there might be a tendency for the rear truck wheels to kick, and thus jump the line, but this is impossible owing to the guard wheels. These are kept hard pressed against the carrying rope by means of springs, and are only forced apart as the car glides over the line supports on the towers, the track wheels passing over the upper face of the shoe, while the guard wheels pass beneath it. Directly the car has passed the tower the guard wheels are forced against the track cable once more.

Elaborate safety devices of various descriptions to bring the car to a standstill under all conditions of accident to the line are incorporated, and it is virtually impossible to precipitate an accident to the vehicle and its occupants. This aerial railway is one of the longest in existence for the carriage of passengers; no fewer than 39 lattice steel pyramid towers, ranging from 21 to 100 feet in height, according to the contour of the ground, are required to support the line. Some of the spans are of considerable length, the longest being about 720 feet. Each tower has two arms for supporting the track on either side, and the carrying cable, $2\frac{3}{8}$ inches in diameter, made up of 238 stranded and spirally wound wires, will sustain a pull of 235 tons before breaking. The margin of safety consequently is very ample. The hauling and braking ropes are one half the thickness of the track cable, and have a breaking strain of 58 tons.

The foregoing European installations may be described as expressions *de luxe* in connection with aerial methods of travelling when compared with the "Sunrise Peak Aerial Railway—The World's Grandest Scenic Route," since in this instance the passengers are accommodated in a large bucket! This line lacks all the finish of its Alpine prototypes, but, on the other hand, it introduces the traveller to most gorgeous scenic attractions. It is about



THE STARTING STATION ON THE KOHLERER AERIAL RAILWAY AT EISACK.

$1\frac{1}{2}$ miles in length, and lifts the sightseer from Silver Plume, at 9,000 feet above sea level, to the summit of Sunrise Peak, 3,500 feet higher.

"To the Clouds in a Bucket" is one of the sensations of Colorado, and it must be admitted that large numbers of people avail themselves of this opportunity to attain one of the eyries of the Rocky Mountains. The railway swings across yawning canyons, and over bleak wind-swept brown humps of the range, in its ever-upward climb. The track comprises a single cable, while propulsion is afforded by the endless haulage cable, $1\frac{1}{2}$ inches in diameter, which passes round a drum at either terminal. The travelling truck is fitted with two wheels each 4 inches in diameter.

"To the Clouds in a Bucket."

The track is carried on supports resembling gallows in shape, made of timber members measuring 8 inches square. There are fifty of these towers distributed over the road, the length of the spans varying according to the mountain slope and the lay of the country traversed. The motive power is electricity, drawn from a generating station four miles away, and drives two 35-horse-power motors, coupled to the winding drums, in the upper station.

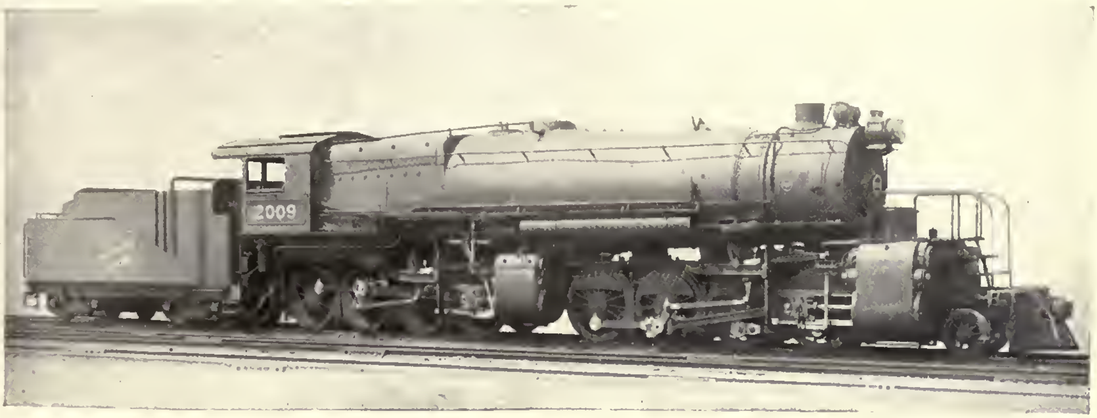
The cars are merely huge buckets, similar to those employed for excavating purposes, and they are slung from the overhead travelling truck. There are 20 buckets on the line, spaced about 485 feet apart. The cars only make a brief stop at the station, and the passengers, in true American fashion, "have to get a move on" to make sure of their seats. Each bucket is strongly made of wrought iron, is 6 feet long by 4 feet wide, and has four seats. The car is entered through a side door, which, when the bucket is loaded, is shut and bolted firmly on the inside. There is no protection from the weather, and should rain be encountered at a higher altitude as though threatening a second deluge, or the sun pour down as if bent upon grilling, the inmates have to suffer in silence unless they have brought suitable conveniences with them.

Although there is a conspicuous lack of comfort or luxury upon this line, it has the compensating advantage of giving the traveller a free, open, inspiring view of gulch, peak, snow, cloud, and torrent from an altitude of 12,500 feet. There are five intermediate stations, built around the upper parts of the cable-supporting towers, each complete with its attendant, and the line is equipped with electric signals and telephones. Should any untoward mishap occur during the journey, the station-master can telephone to the engineer to stop the line, and communicate the nature of the accident.

An Altitude of 12,500 feet.

This line demanded some three years in its construction, and although undeniably primitive, it involved an outlay of £14,000. It has proved a unique success, the touring public evidently tolerating imprisonment within a confined space for half-an-hour each way with the utmost good humour. "It is easier than climbing, anyway," comment the patrons of this railway, "and a darn sight quicker!"

The success of the aerial railway is so marked that a new era in railway mountaineering has dawned. There is no doubt but that in the future this method of scaling lofty peaks for the benefit of the tourist will undergo considerable development, and will be preferred generally to the cog-wheel and incline railways which have had such an extensive vogue. Certainly it will offer a means of carrying passengers to the crests of towering mountains which otherwise would be inaccessible by any other railway system, since no mountain flank is too precipitous for this type of line.



THE "BIG BULL-MOOSER" OF THE GREAT NORTHERN RAILROAD. U.S.A.
This Baldwin-Mallet compound locomotive (2-8-0, 0-8-0) is used for the heavier class of traffic—passengers and goods—among the mountains. Total weight, with tender, 300 tons.

Locomotive Giants—I

SHOWING THE DEVELOPMENT OF THE HUGE AMERICAN LOCOMOTIVES

ONE of the most remarkable features of railway operation during recent years has been the development of the mammoth locomotive. The era may be said to have commenced in France, but it is the Americans who have brought this movement to its highest pitch of perfection.

The issue was forced upon the United States and Canadian railways. The necessity to haul immense loads, such as coal, ores, grain, etc., over long distances without breaking bulk, often struggling against heavy grades, presented peculiar difficulties. The eight, ten, or twelve-ton wagon common to the British railways became absolutely useless, because therewith, owing to the immense volume of the traffic to be handled, the lines would have become choked throughout the twenty-four hours with unwieldy long trains. During the year the United States railways have to handle over 1,500,000,000 tons of goods, which is about one-sixth more than that moved on the combined railways of the United Kingdom, Germany, France, and Russia in the same period.

Under such circumstances the futility of the small wagon may be appreciated. But there was another factor which influenced the situation very vitally. With the small wagon the proportion of "live" or paying tonnage in a train is small in comparison with the "dead" or non-paying train tonnage, while more train-miles have to be run in order to cope with the transportation of a certain volume of traffic. The point was to reduce both the number of train-miles and the proportion of the dead load. This could be accomplished only by introducing larger vehicles. Accordingly there came the 30-ton wagon, which enabled the train to be shortened very appreciably.

Once this development started it went ahead rapidly. The vehicles were increased in capacity, until to-day there are cars on

the American and Canadian lines capable of carrying 75 tons.* This means that when 5,000 tons of coal, ore, grain, or what not have to be moved a matter of ten or fifteen hundred miles, a single American train of 40 vehicles will handle what would require 300 British 10-ton trucks. The operating expenses thus are decreased, as well as the train-miles, while the income per train is increased.

But the augmentation of the load per train precipitated another problem. The hauling power of a locomotive became overtaxed, so that it was necessary to utilise two engines to a train; while for the negotiation of long steep banks through the mountains additional power had to be taken on, to push and haul the load over the hump, or else the train had to be divided and run in sections over the obstacle.

The Locomotive Problem.

The locomotive engineers were urged to evolve larger and more powerful engines to dispense with "double-heading" and division of trains. This problem was not easy to solve, owing to the designer being cramped by the comparative narrowness of the standard gauge. The engineer increased the length and diameter of his boiler until he was unable to go another inch in either direction. Even then he encountered harassing difficulties in connection with his fire-box and the complete combustion of his fuel. Additional driving wheels were introduced to secure the maximum adhesion and tractive effort, and remarkable ingenuity was displayed in order to secure efficient steaming qualities.

In this search for greater locomotive power many striking and interesting types of engines were evolved, some of which are foreign to British working. Among these were such huge creations as the "Consolidation," the "Mastodon," and the "Mikado," with eight large drivers, the distinction between the types being attributable to the arrangement and number of the leading, trailing and driving wheels.

Here it may be as well to describe how locomotive types are classified. The colloquial descriptions such as "Atlantic," "Pacific," "Baltic," "Consolidation," and so on are somewhat confusing, inasmuch as they convey no idea of the arrangement and number of the wheels. So the Whyte numerical system has come into general vogue as conveying the wheel disposition most satisfactorily. In this classification the wheels are divided into three groups, viz.—leading, bogie, or pony truck; drivers; and trailers. Thus an engine set out as of the 4–4–2 class indicates that there is a four-wheeled pony truck, followed by four drivers, and two trailing wheels, forming the familiar "Atlantic" type. If there are no leading or trailing wheels, or if one or the other be omitted, the absence is indicated by a cipher. Thus the numerical classification of a "Consolidation" locomotive is 2–8–0, signifying a two-wheeled bogie, eight drivers, and no trailing wheels; the "Mastodon" 4–8–0, with a four-wheeled bogie, eight drivers, and no trailing wheels; the "Mikado" as 2–8–2, representing a two-wheeled pony truck, eight drivers, and two-wheeled trailer. In view of the manner in which the locomotive engineers "have rung the changes" on the arrangement of the wheels, the Whyte numerical classification offers the simplest and most comprehensive method of nomenclature.

Classification of Locomotives.

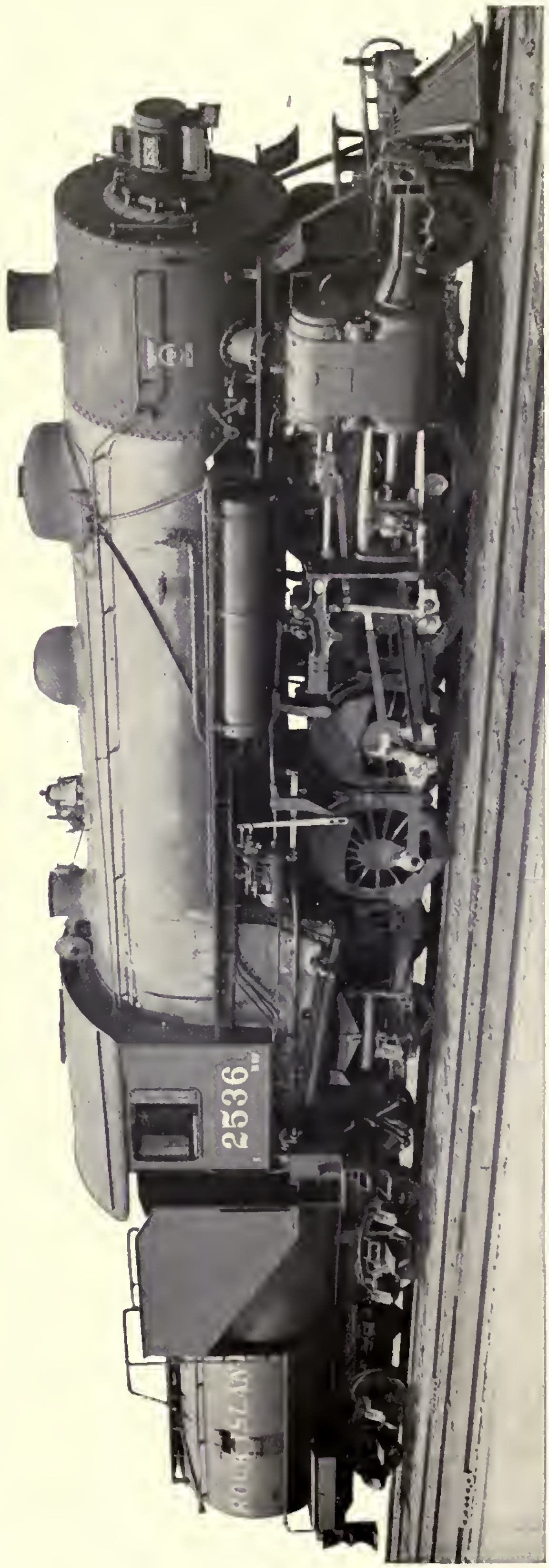
It was conceded generally that the ten driving wheel locomotive represented the limitations of design with a rigid wheel base. While engineers were racking their brains as to how to obtain greater power there appeared an invention which changed completely the whole problem of locomotive design. This was the articulated engine, as evolved by M. Anatole Mallet, of Paris.

Mallet's Articulated Engine.

* The American ton of 2,000 pounds, and gallon equivalent to ·8 Imperial pints are used in the references to U.S.A. locomotives.

A PENNSYLVANIA RAILWAY GIANT'S RECORD.

The train consisted of 120 steel cars laden with coal, of a total weight of 8,850 tons, and measuring 4,888 feet in length. This engine hauled its load a distance of 127 miles in 9 hours 36 minutes.



A POWERFUL BALDWIN "MIKADO" (2-8-2).

One of the largest of its type yet built for freight service on the Chicago, Rock Island and Pacific Railway. The locomotive complete weighs 240 tons. The Vanderbilt cylindrical water tank carries 9,000 gallons.

Its appearance on the French railways created a sensation. American engineers, realising its advantages, and the fact that therewith it was possible to obtain that increase in power which was demanded so urgently, embraced the idea forthwith.

The outstanding feature of the Mallet locomotive is the division of the frame into two parts, which are connected together by a hinged joint. Each section of the frame carries a set of driving wheels and a pair of cylinders. In this way it is possible to obtain an engine having as many as twenty driving wheels—in two groups of ten each—and no more resistance is encountered in rounding curves than with an Atlantic engine. Compound working is adopted, the high pressure cylinders driving the inner, while the lower pressure cylinders drive the foremost group of wheels.

These monster engines for the most part are utilised for three distinct services—express; pusher, to assist trains over steep grades; and the haulage of long, heavy freight trains. They are giants in the fullest sense of the word. For instance, the Great Northern "Big Bull Moosers" used on the Rocky and Cascade mountain divisions turn the scale, engine and tender complete ready for the road, at 300 tons, while the wheel base is 83 feet 1 inch. The high pressure cylinders have a diameter of 28 inches, while the low pressure cylinders are 42 inches diameter, the stroke being 32 inches. The Belpaire conical boiler has a diameter of 90 inches; the fire-box a length of $117\frac{1}{4}$ inches by $96\frac{1}{4}$ inches wide, and $87\frac{1}{4}$ inches deep

in front and 76¼ inches at the back. There are 332 tubes, each 24 feet in length, 2¼ and 5½ inches in diameter. The fire-box has a heating surface of 245 square feet; the combustion chamber 81 square feet; tubes 6,120 square feet; giving a total heating surface of 6,446 square feet. The grate area is 78·4 square feet. The driving wheels are 63 inches, and the truck wheels 33½ inches in diameter respectively. The driving wheel base is 43¾ feet in length, with 16½ feet for the rigid base, bringing the wheel base of the total engine to 52½ feet. The weight on the drivers is 210 tons, and on the front truck 15 tons. The tender, mounted on eight wheels, each of 36 inches diameter, carries 8,000 gallons of water and 13 tons of soft coal which is used as fuel. The engine is also fitted with an Emerson superheater, having a surface of 1,368 square feet. The working pressure of the steam is 210 pounds per square inch. It exerts a tractive force of 100,000 pounds.

This articulated Mallet engine, built by the Baldwin Locomotive Works at Philadelphia, has proved highly successful in the heaviest class of mountain service.

The Pennsylvania Company's Giant.

The Pennsylvania Company also have designed a very powerful locomotive, classified by the company as the H–8–b type, for its heaviest freight service. This engine has four pairs of 62-inch driving wheels, with a two-wheeled pony truck, 2–8–0 class. The total length of the driving-wheel base of the engine is 17 feet 0½ inch, of the engine 25 feet 9½ inches, and of the engine and tender 59 feet 5⅝ inches. The cylinders have a diameter of 24 inches with a stroke of 28 inches. The Belpaire wide fire-box is used, being 110¼ inches long by a width of 72 inches, the total heating surface being 187 square feet. The boiler has a minimum internal diameter of 76¾ inches; there are 465 tubes of 2 inches outside diameter, the total heating surface of the tubes being 3,652 square feet. Steam is used at a pressure of 205 pounds per square inch. The weight of the engine in working order is 119·15 tons, of which 105·5 are upon the driving wheels. In working order the 8-wheel tender weighs 79 tons, the complete weight of the locomotive therefore being 198·15 tons.

A Train 4,888 feet in Length.

An interesting experiment was carried out with this engine in order to ascertain the precise freight-carrying possibilities of the 127 miles between Altoona and Enola Yard, opposite Harrisburg, Pennsylvania. This section of the system has been overhauled and reconstructed so as to secure no heavier rise than 12 feet per mile.

Engine No. 1221 of the H–8–b type was attached to a train of 120 steel gondola cars laden with coal. Each wagon carried 52½ tons of mineral, so that the total consignment represented 6,300 tons. The complete weight of the train, including engine, cars, and brake-van, or caboose, was no less than 8,850 tons. From end to end this train measured 4,888 feet—more than nine-tenths of a mile.

Telephone from Driver to Guard.

Despite the huge load the one engine, having a tractive power of 42,661 pounds, hauled the train over the distance of 127 miles unaided, occupying 9 hours 36 minutes on the journey, giving an average speed of 13 miles an hour. As, however, this time included delays aggregating some three hours, the actual running speed averaged 19 miles an hour. In making the trip the engine consumed over 13 tons of coal.

A unique feature of the train was a telephone connection between the brakesman in the rear van and the driver of the locomotive, the wires being carried along the sides of the vehicles.

While the Pennsylvania Railway Company has no intention of operating such

trains regularly, yet from time to time it embarks upon such tests to determine the capacity of its freight locomotives over the improved lines, where grades have been removed and curves compensated.

Recently some very powerful "Mikados," among the largest and most powerful of the 2–8–2 type, have been constructed. The Baldwin Locomotive Works have supplied some of the largest of this class yet built for the Chicago, Rock Island, and Pacific Railway, for service upon its system where no excessively steep grades are encountered. The characteristic feature of this design is the boiler, which is constructed with a wide and deep fire-box, 84 inches wide by 90 inches deep at back, and 77 inches deep at the front. The grate is placed behind the driving wheels and above the trailers, thus obtaining a large amount of grate area and furnace volume. The boiler is 86 inches in diameter, the tubes 21 feet long, having a total heating surface of 4,004 square feet. The driving wheels are 63 inches in diameter. The engine has a length of 35 feet 2 inches, the over-all length of the locomotive being 67 feet 2½ inches. The weight imposed on the drivers is 121·6 tons, while the total weight of the engine and 8-wheel tender, the latter loaded with 16 tons of soft coal and 9,000 gallons of water, is 240 tons.

A Huge "Mikado."

Another well-known system, the Delaware, Lackawanna, and Western Railroad, has also introduced fifteen Mikados of much greater sustained capacity than those hitherto used in its service. They have been constructed by the American Locomotive Company, and are being employed in the slow and fast goods service between Elmira and Buffalo.

The boiler, 86½ inches in diameter, has a total heating surface of 4,592·8 square feet, and works at a pressure of 180 pounds per square inch. The fire-box is 108 feet long by 74¼ inches wide. The cylinders are of 28 inches diameter and 30 inches stroke. The grate area is 63·1 square feet, and the total heating surface 4,854·1 square feet with 1,085 square feet of superheater. The drivers, 63 inches in diameter, carry a weight of 118·75 tons, the total weight of the engine in working order being 156 tons. The 8-wheel tender, loaded with 14 tons of soft coal and 8,000 gallons of water, weighs 79·85 tons, bringing the complete weight of the locomotive to 235·85 tons.

Weight, 235·85 tons.

These engines, with a maximum tractive power of 57,000 pounds, are superseding Consolidation locomotives, having cylinders of 26 inches diameter by 30 inches stroke, and a theoretical maximum tractive power of 51,400 pounds, in the slow freight traffic, while in the express goods service they are replacing Mogul—2–6–0 class—with cylinders 20½ inches diameter and 26 inches stroke, and a maximum tractive power of 29,480 pounds. Although these Mikados have the same cylinder stroke as the superseded Consolidation engines, they have drivers of 63 inches instead of 57 inches. So far as the Moguls are concerned, these Mikados have almost 100 per cent. greater capacity.

Among the most impressive, and largest, as well as the most powerful engines yet constructed, the Mallet compounds built by the Atchison, Topeka, and Santa Fé Railway, forming what are known as the "3000" class in the railway's service, stand preeminent. The engine alone weighs 308 tons, of which 275 tons are distributed over the twenty driving wheels, the articulated classification being 2–10–0, 0–10–2. The tender weighs 117 tons, bringing the total weight of the locomotive in running order up to 425 tons. Its length over all is 120 feet 7½ inches.

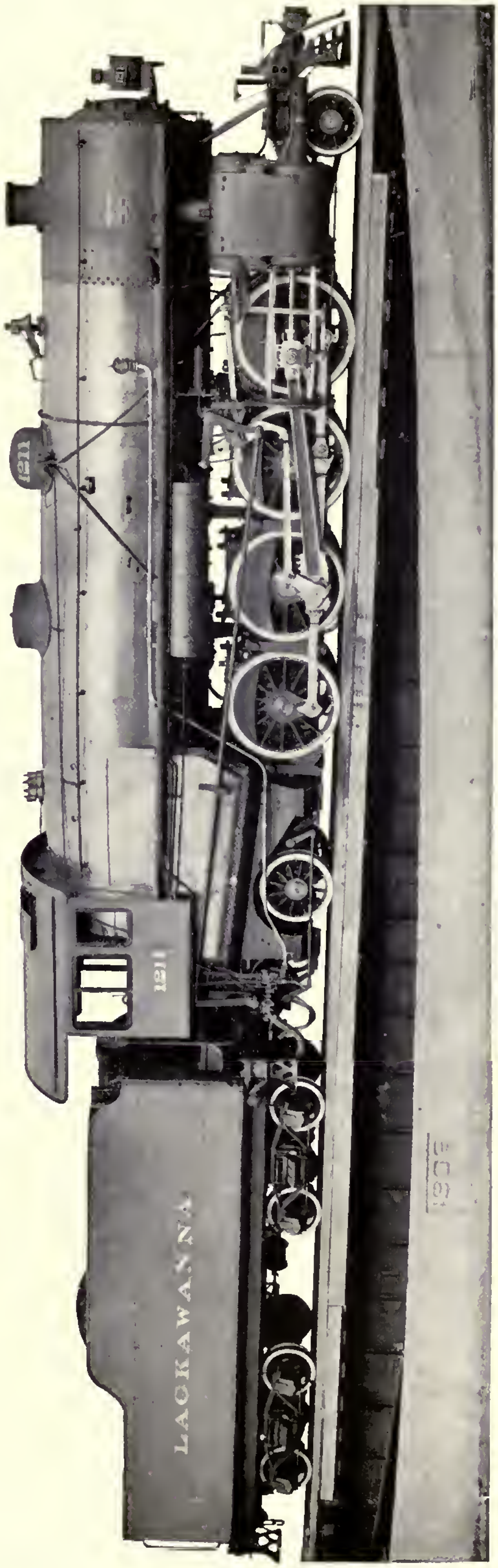
The "3000" Class.

The high and low pressure cylinders respectively are of 28 and 38 inches diameter, with a common stroke of 32

inches. The fire-box, 149⅝ inches long by 78 inches wide and 76 inches deep, has 294·5 square feet of heating surface. The 377 fire tubes have a heating surface of 3,625 square feet, while the superheater has a surface of 2,318·4 square feet. There is also the re-heater, and finally the feed-water heater, the tubes of which have a heating surface of 2,659·4 square feet. The introduction of the superheater, re-heater and feed-water heater represents the latest development in locomotive engineering, the functions of which are described later.

The driving wheels have a diameter of 57 inches, while that of the truck wheels is 34¼ inches. The tender is carried on twelve wheels, and has capacity for 12,000 gallons of water and 4,000 gallons of oil, liquid fuel being used, while the working pressure of the steam is 225 pounds per square inch.

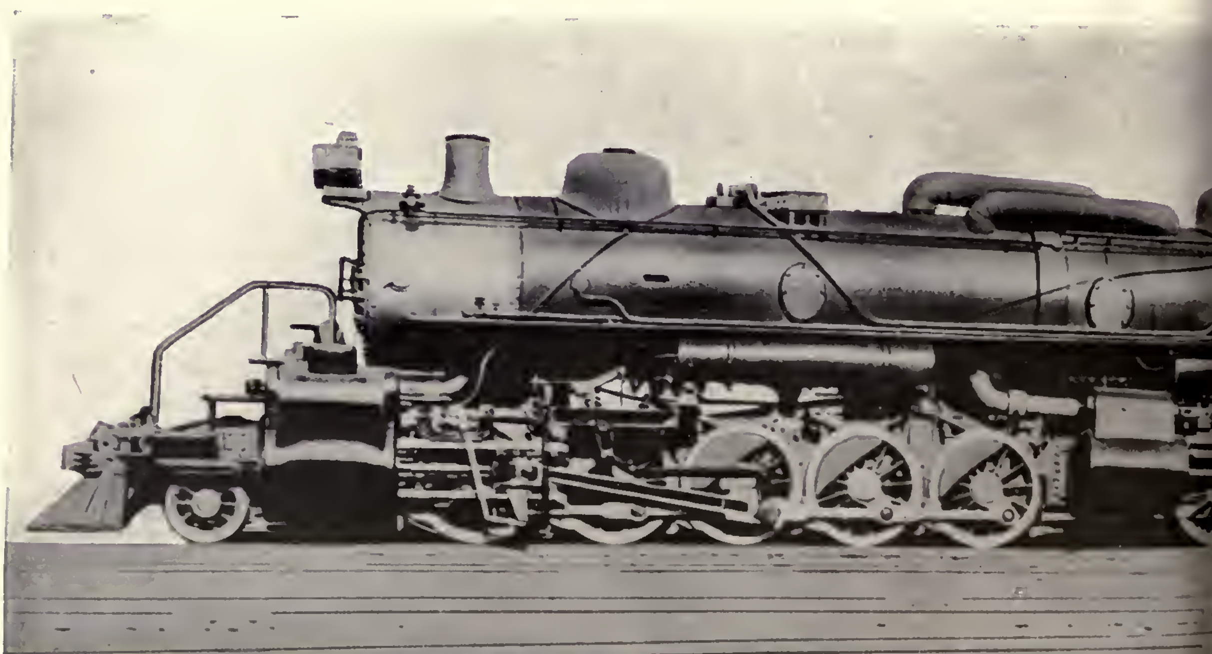
This huge locomotive has a maximum drawbar pull of 111,600 pounds, and in an experimental run to ascertain its hauling capacity one of its class drew a train of 100 loaded freight cars, representing a live weight of 4,341 tons, from Emporia to Argentine, a distance of 111·5 miles, where the maximum grade is 21 feet per mile, in 6 hours 20 minutes. It has hauled a load of 1,911 tons at a speed of 12 miles per hour over a grade rising 79·2 feet per mile. At a speed of 10 miles per hour the engine develops some 3,000 horse power. At present these engines are being utilised for the most part in territory served by the Atchison, Topeka and Santa Fé Railway, where the ruling grade is 90 feet per mile, the train-loads upon this division averaging 1,900 tons, and the speed ranging between 12 and 15 miles per hour. Other locomotives of this class are reserved for pusher service, to assist the regular trains over Cajon Mountain in California, where the grade runs as high as 180 feet per mile. These Santa Fé giants have aroused world-wide interest.



A DELAWARE, LACKAWANNA AND WESTERN RAILROAD MAMMOTH.
Its weight in working order, with loaded tender, is 235·85 tons.

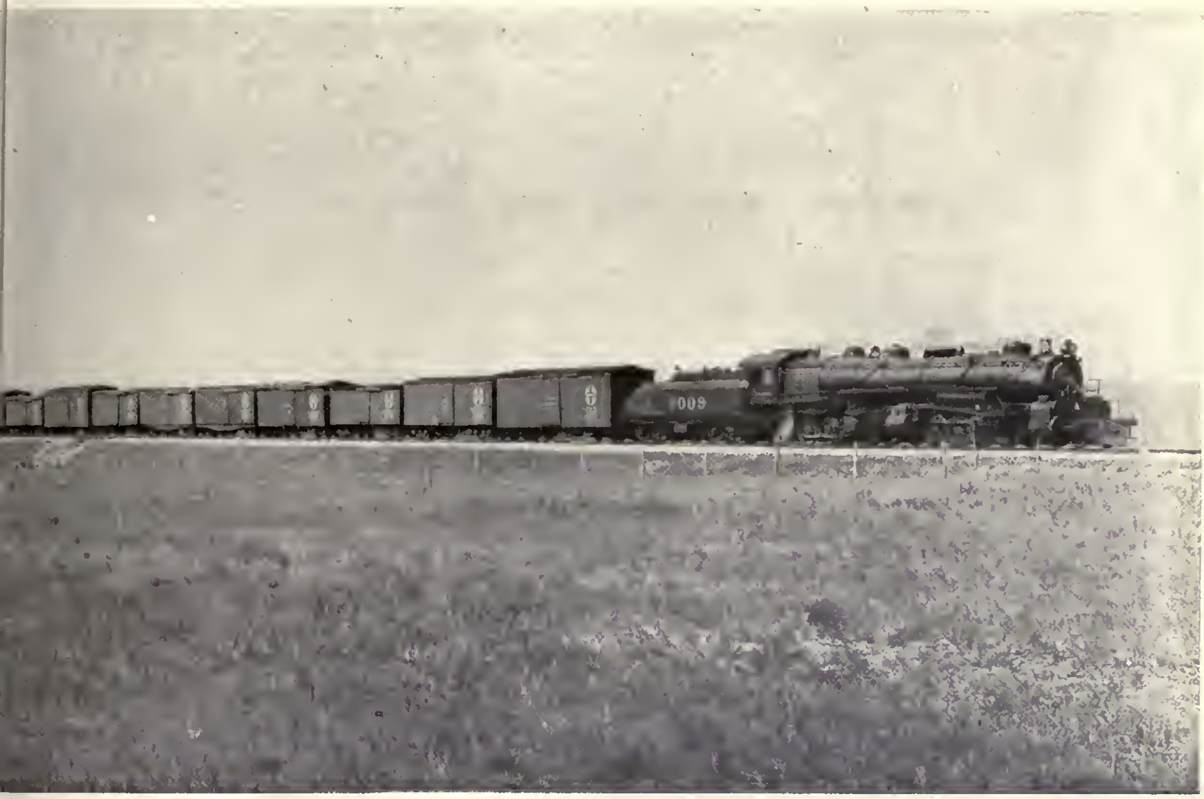
A TEST LOAD FOR ONE OF THE "3000

The run was from Emporia to Argentine, 111·5 miles, with a load of 100 cars, which extended ov



THE GIGANTIC MALLET COMPOUND BUILT FOR THI

The engine weighs 308 tons, and the tender 117 tons, a tota



LASS LOCOMOTIVES SHOWN BELOW.

000 feet, and represented 4,341 tons weight. The journey was accomplished in 6 hours 20 minutes.

ATCHISON, TOPEKA AND SANTA FÉ RAILWAY.

f 425 tons. Its length over all is 120 feet 7½ inches.

THE DOUBLE-LIFT BRIDGE AT PORTLAND OREGON.
End view of bridge showing flared ends to the railway and the approach to the upper level.

A Telescopic Double-Lift Bridge

AN INGENIOUS ENGINEERING DEVELOPMENT TO COPE WITH RAILWAY, SHIPPING AND VEHICULAR TRAFFIC

ONE of the most perplexing situations in railway building is the necessity to cross a busy waterway at a low level, owing to the physical characteristics of the banks on either side. In order that no serious restriction may be imposed upon navigation, it is imperative that the bridge shall be provided with some means of opening so as to permit vessels to pass up and down easily. When this handicap is associated with a busy city, spreading over the opposite banks, the problem becomes aggravated, as the engineer is cramped for space in which to achieve his object.

Many ingenious methods have been elaborated to meet such conditions. There is the swing bridge, in which a span of the bridge is able to swing round in a semicircle upon a pivotal pier, thereby providing two channels—one on either side of the support. Another expedient, which has come into vogue extensively during recent years, is the bascule bridge, in which the moving section of the structure, being hinged at one end, is raised and lowered like a drawbridge. A third method, which, however, is not employed very freely, is the vertical lift bridge, wherein the span is raised bodily in conjunction with counterweights, between two supporting towers,

this system being similar in its principle and operation to the sash-line window.

Recently a new and ingenious development in connection with the last named method has been introduced. It is the patent of two American engineers, Waddell and Harrington, and it possesses many interesting features. The Oregon-Washington Railroad and Navigation Company desired a new entrance into the city of Portland, Oregon. The Willamette, which divides the city in twain, is a broad, deep river, enabling large vessels to reach this point from the sea.

The Requirements of the Service.

When the railway first entered the city it built a large steel bridge with a swing span, which it was concluded would meet all the requirements of navigation and yet at the same time would not hinder railway operations. But the trade of the port has increased amazingly during recent years, with the result that the swing span was constantly having to be opened and closed. On the yearly average this occurred 70 times a day—practically once every 20 minutes—while in one interval of 24 hours it has been opened as many as 134 times.

Such frequent manipulations handicapped the railway traffic very seriously, so the company decided to build a new bridge across the waterway, 700 feet above the original swing bridge. This decision was seized as an opportunity to improve the vehicular and pedestrian traffic between the two banks, so a double deck bridge was adopted, the lower deck being for the railway, and the upper level for public use. But the question of protecting the navigation interests arose. The various methods of operating a moving span economically and expeditiously were investigated at length. In this case the problem was complicated by the top deck used by the public, which it was essential should be kept open as much as possible so that inconvenience to vehicular and pedestrian intercommunication might be reduced to the minimum. Obviously, both the swing and bascule systems had to be ruled out of court, because it was impossible to place the upper deck at such a level as to be beyond interruption at intervals. It was a peculiar problem which demanded a special solution. The railway engineers thereupon investigated the Waddell and Harrington invention, and finding that it met the situation very completely, it was adopted forthwith.

Swing Bridge Inadequate.

The river channel is crossed by three spans—a fixed span 287 feet in length on either side, flared at the shore ends to provide for the necessary curvature of the railway lines, and a centre movable span 220 feet long. The public deck of the bridge being nearly 50 feet above the level of the railway, suitable approaches at the ends had to be provided to secure an easy grade. That at the east end is by means of a viaduct 305 feet in length; on the west bank there is a highway approach 512 feet long. Thus the over-all length of the structure is 794 feet for the railway, and 1,611 feet for the public use.

A Double-Deck Bridge.

The moving span, which rises vertically between two towers by means of counterweights, is telescopic. That is to say, the moving span is so built that the lower deck may be raised independently of the upper deck. This is a distinct advantage, inasmuch as this vertical travel amounts to 46 feet. Accordingly, when the railway deck is raised until it touches the floor of the upper deck, a clearance of 72 feet above low water is secured. This is sufficient headroom for the greater proportion of the river traffic, so that there is no necessity to disturb the public highway. When, however, a large vessel with tall masts approaches, demanding a greater clearance, the bottom deck first is tele-

A Telescopic Span.

THE BRIDGE OPEN FOR VEHICULAR, PEDESTRIAN, AND TRAIN SERVICE.
The trains run over the lower deck.

scoped, and then, together with the higher level of the span, is lifted until the whole moving part comes to rest near the top of the towers, whereby a clearance of 165 feet at low water is given. By this provision all but the very largest craft coming to Portland are able to proceed through the bridge.

The independent movement of the bottom deck is accomplished by supporting the railway floor system and lateral truss on hanger posts from the upper movable span. Each hanger is connected to four cables, and is designed to move vertically inside the corresponding vertical post of the upper movable span. Both railway and public decks are counterbalanced with concrete weights. The lower moving section has eight of these counterweights, disposed four on each side, each section of four having an aggregate weight of 212 tons. The upper deck has two similar weights, each weighing 866 tons.

The river piers were sunk by the open caisson method. These were landed on cement gravel at a depth of 123 feet below low water. The six dredging wells were excavated to a depth of 10 feet below the cutting edge of the caisson, and the concrete was deposited under water by means of bottom dump buckets. In the completion of the sub-structure work some 30,000 cubic yards of concrete were used.

The steel viaduct carrying the highway approach on either side was erected by means of a 30-ton skid derrick, having a boom 45 feet in length. This plant also set the upper floor system and laterals for the fixed spans, as well as the lower members of the two towers, the heaviest single piece which it was called upon to handle weighing 29 tons, represented by a beam for the upper deck. The two fixed spans were erected by the aid of timber falsework, which was built upon the double bent system with 22 piles. For the raising and placing of the truss members and the lower floor a barge, or scow, derrick was devised.

This had sheer legs 110 feet in length, fashioned from four heavy piles. By means of this apparatus a chord section weighing as much as 54 tons was set in position.

The building of the vertical lift span, and the movable railway deck, had to be carried out in such a manner that no interference was offered to the river traffic, and also in such a way as to be as independent as possible of the level of the water in the river. A clearance of 116 feet above low water was considered to be sufficient for the purpose. Four wooden cantilever brackets were put together on barges, and by means of the floating sheer-leg derrick were hoisted in position on the adjacent ends of the fixed spans. The bases of these brackets rested on the piers, while the tops were anchored to the fixed spans by means of iron rods $2\frac{1}{2}$ inches in diameter, four rods being used for each bracket. The two skid derricks then were rigged with booms 110 feet in length, and by their aid four Howe trusses, measuring 120 feet long, and weighing 40 tons each, were lifted and set upon the timber brackets. The iron required for this falsework was fashioned from the scrap of old spans removed from the railway company's line several years previously.

In the erection of the two towers carrying the counterweights, as well as the sheaves, a gallows-frame, 152 feet in height, was built and lifted into position on top of the Howe truss falsework. This was anchored back to the truss and hinged at the base, so as to obtain sufficient rotation to set any members of the towers into the requisite position. The heaviest lift which this gallows-frame effected was the section of a tower post weighing 42 tons. The steel used in the erection of the towers was loaded on to cars which were run out to the site over the railway deck. They were hoisted through a hole in the upper deck, this having been obtained by leaving out the stringers

THE BRIDGE OPEN FOR VEHICULAR AND PEDESTRIAN TRAFFIC ONLY.
The lower deck raised so as to telescope within the upper span.

of two panels of the latter, sufficient clearance thus being provided to permit the passage of the largest sections of steel.

The members of the lift span were handled by a traveller 96 feet in height. A construction tramway was laid on the upper deck of the east span and viaduct, over which a "creeper" car travelled. The steel was brought up on cars to the viaduct, and a derrick hoisted the sections therefrom on to the creeper car, which was then run out to the erecting point.

While the lift span was being built the casting of the concrete counterweights proceeded. These were prepared in their ultimate positions within the towers. The forms whereby these weights were moulded rested on boxes containing a layer of sand 18 inches in depth, and the moulds were placed 18 inches above the position they were to occupy ultimately. By this arrangement sufficient play for the stretch of the ropes, and to provide requisite ease in connecting the cables, was ensured. After the concrete had set, and directly the lift-span was completed, the sand was permitted to run out of the boxes, so that the weights gradually descended to their requisite level and took up the ropes, thereby swinging, or taking up the weight of the lift span, so as to enable the falsework to be demolished.

THE BRIDGE OPEN FOR SHIPPING.
The lower span is telescoped and the whole lifted so as to give a clearance of 165 feet on the navigable channel. The descending counterweights close the thoroughfare on the public level of the bridge.

The lower or railway deck of the movable span was erected in sections on barges, a floor beam and two hangers first being riveted up, and then raised into position. The concrete counterweights for this deck were cast separately for each panel joint, and they were previously cast and supported on falsework on the upper deck. So soon as a panel joint was in place it was connected to its cables and supported by the counterweight. All the hanger posts,

with the floor beams, were set first, the stringers and lower lateral truss being filled in subsequently.

By these ingenious arrangements the construction of the most difficult section of the bridge—the moving span—was completed without any material interference to navigation. All river traffic was able to pass to and fro without the slightest hindrance. The methods adopted furthermore secured rapid construction.

The machinery house for the operation of the moving sections is placed centrally on the deck above the highway level of the bridge. The mechanism is operated electrically. A large gauge is provided on either side of the bridge extending from the top of the piers to the point corresponding with the level of the telescoping railway deck, so that the navigator can determine the clearance available both when the lower deck and when the two spans are raised to the full limit of their respective travels. When the public level is lifted, the two descending counterweights block the thoroughfare on either side of the opening.

The total weight of the bridge is 8,585·8 tons, divided up as follows :—

West highway approach .	687	tons
East highway approach .	398·8	,,
Four 80-feet deck railway girders	103	,,
East riveted span . .	2,230	tons
West riveted span . .	1,948	,,
Lift span with lifting deck .	1,594	,,
Towers	799	,,
Tramway poles, balustrade, gas and water mains, etc. .	342	,,
Machinery and motors. .	484	,,

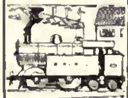
while its total cost was £383,000.

The bridge was completed for railway traffic on July 23rd, 1912, while the public highway was finished a fortnight later. Since it was opened, the chief engineer of the railway informs me that the bridge has been working with perfect and entire satisfaction. The time occupied in raising both decks to the maximum clearance above low water—165 feet—is $1\frac{3}{4}$ minutes, while lowering requires a similar interval. The result is, that when a sea-going ship with high masts desires to pass through the bridge, the public traffic on the upper deck is interrupted for five minutes. As the bulk of the navigation, however, demands only the moving of the lower or railway deck, the interference offered to vehicular and pedestrian traffic is so slight as to be insignificant. The unique success of this installation doubtless will lead to the wider adoption of the idea where similar conditions prevail, and where it is often essential to utilise a bridge both for public and railway services.

LEVELLING AND BALLASTING THE LINE.
The work was done entirely by negro labour

The Railway Invasion of the Gold Coast

HOW THE SEKONDI-COOMASSIE RAILWAY WAS DRIVEN THROUGH THE PRIMEVAL FORESTS



WHILE every great railway possesses its individual romance, yet, tucked away here and there, in odd corners of the globe, are short isolated lengths of the steel highway which claim more than ordinary attention. Among these are the railways of West Africa, and in particular that of the Gold Coast, which possesses a romantic glamour which is peculiarly its own.

The popular conception of this section of the African continent is somewhat hazy. Generally it is dismissed as "The White Man's Grave," comprising vast tracts of dense, impenetrable, fever-laden jungle, concealing lagoons and swamps, where death lurks unseen in a hundred different forms. This impression, however, is quite wrong. The country certainly has a climate which is far from kind to the white man at present, in the same manner as the frost-bound wilderness of Canada was a certain death-trap until the pioneers opened it up to let in the sunlight. As West Africa becomes settled and deve-

loped, the insalubrious conditions will disappear; the country will be rendered as tenantable and as attractive as the southern extremity of the continent.

The idea of criss-crossing these vast expanses of virgin territory by the railway was suggested first by Mr. (afterwards Sir) William Shelford, M.Inst.C.E. Railways were the obsession of this accomplished engineer, and he concentrated his activities and skill upon West Africa. In the early nineties of the last century he attacked the problem vigorously, because he foresaw that, once this untouched region was given a fair start, settlement and development must go ahead with a rush.

At that time West Africa was a veritable "Tom Tiddler's Ground," awaiting the coming of the capitalist and toiler. But the machinery of development could not be set in motion until facilities were offered for access to the interior. The shore of the Gold Coast is hemmed in by a thick belt of jungle, 150 miles or more in width. To venture into this huge, untrodden forest demanded no small amount of pluck and determination. The exotic vegetation presented a solid barrier, through which advance could be made only by hacking and cutting, since the jungle was intersected by very few, narrow, and tortuous paths, trodden down by the feet of the natives.

BUILDING UP THE GRADE TO TRACK LEVEL.

The railway conquest of West Africa was inaugurated with the dispatch of a survey party to Sierra Leone in 1893 by Mr. Shelford, the Colonial Office having decided to open up the hinterland. Actual constructional work was commenced in 1896. Step by step the railway, of 2 feet 6 inch gauge, was driven forward from Freetown until it had reached Pendembu, 230 miles up country, and a short distance from the Liberian frontier.

The first attempt to survey the unknown interior for the ribbon of steel proved disastrous. Three Englishmen started out to make the reconnaissance. The party comprised a surveyor, his assistant, and a doctor. The latter was indispensable, owing to the country's evil reputation. Disease was more to be dreaded than any form of hostility or accident. The surface of the ground is carpeted with a thick layer of decaying vegetation—the putrefaction of centuries—and the rainfall, which is severe, has converted this bed of leaves, branches, and dead-fall into a spongy, soddened mass, freely interspersed with pools and swamps, where the mosquito and other pests multiply by the million. Accordingly, malaria is rife; in fact, at that time it held the country more securely against a white invasion than the most cunning and determined tactics of the unfriendly natives.

A Malaria-ridden District.

The trio had not gone far before the formidable character of their undertaking was revealed very vividly. The swarming implacable insects counted their first victory: the doctor was bowled over by malaria. This was the sorriest trick that fortune could have played, and it was decidedly unnerving. Then the assistant fell a victim to the malady, and before the gravity of the situation was grasped he had crossed "The Divide." It is not surprising that the surveyor himself, who had cheated misfortune, was dismayed by this calamity. His first care was the interment of his dead chum. He gave him as Christian a burial as the limited circumstances of the bush permitted. The provisions were tumbled out of the thin wooden boxes in which they had been packed for transport, and from these few sticks a crude coffin was contrived, in which the body was committed to a hastily-dug grave. As the doctor was recovering slowly, the surveyor packed his traps and made a laboured, painful return to the capital, where, after the grim story was related, arrangements for another dash through the inhospitable interior were prepared.

An Unfortunate Expedition.

It was the discovery of gold which prompted the construction of the first railway on the Gold Coast. Intrepid prospectors braved the pestilential forests and diligently panned the up-country streams. They discovered traces of colour, and, following up the clues, at last struck the main reef of yellow metal at Tarkwa, some 40 miles from the seaboard. The news of the discovery precipitated the inevitable rush, as well as an inflow of capital, but it was no easy matter to gain the alluring gold belt. There were no facilities for transporting the essential heavy and cumbersome machinery to the claims, while the conveyance of the yellow fruits of exhausting labour to the coast was just as laborious. Incoming vessels had to discharge into small boats which ran the gauntlet of the heavy surf and dodged the sand-bars which littered the waterway leading to the interior. They crept up the river with considerable difficulty to a point as near the mining area as possible and there unloaded. The material then had to be tugged, pushed, and carried over rude tracks through the jungle to the mines. By the time the mines were reached transport charges had run away with £40 per ton.

Gold as the Incentive.

No industrial concern could work under such conditions and show a profit. Accordingly it was decided to drive a railway from a convenient point on the coast to Tarkwa. After scouring the shore line of the Gold Coast from end to end, it was decided to create a terminal port at what was virtually an unknown spot, which then was little more than a native village—Sekondi. It is not a harbour, but merely a small, open bay; but it was the only choice between two evils. Possibly, some

A TEMPORARY BRIDGE OVER THE SUYAM RIVER.
This view shows the nature of the country through which the railroad runs.

day, when the colony attains a position of greater prosperity, and in view of the fact that Sekondi occupies a strategical position in relation to the developed interior, harbour works will be taken in hand, to remedy the deficiencies of Nature for the safety and convenience of shipping.

Having secured a foothold on the coast, the railway builders undertook to drive their line forward from that point. The first section comprised some 40 miles, but it was as hard a 40-mile stretch as any engineer could wish to tackle. There was the densely-matted jungle, a fearful climate, a fiendish rainfall, and a comparative absence of gravel with which to carry out the earthworks. Englishmen, of course, were in demand to superintend operations; but it proved to be no white man's land in those early days. The deadly climate mowed them down like flies, while some of stronger physique, although they outwitted the "old man with the scythe," went raving mad.

Yet the surveyors had painted the picture of what was to come very convincingly. Events proved they did not exaggerate the conditions one whit. They themselves had had many a stiff struggle to advance. Driving survey lines through a gloomy forest which is so dense and overgrown with brush that it is seldom a clear view 100 feet ahead can be obtained is despairing toil. The country was found to be gently undulating, but the majority of the depressions were filled with swamp or stagnant, fetid pools, concealed from sight by the overgrowing scrub, so that a sudden immersion to the thighs or waist was by no means uncommon; while such unseemly disturbance of a silent lagoon was sufficient to provoke dense swarms of mosquitoes to spirited attack.

BUILDING THE ANCOBRA BRIDGE.
The most important on the line. The central span is of 180 feet.

In such country as this the man with the transit and level must be gifted with what the American terms aptly "a nose for a railway," meaning an instinct, cultivated by prolonged and difficult experience, to obtain the best route in the shortest time and with the minimum of expense. When the outlook is shut in on all sides by dense vegetation, it is a toss-up whether the line already plotted is really so good as one which might be found a few miles to one side or the other. Still, each of half a dozen different routes is certain to possess superior features here and there. The problem is the selection of the line which offers the greatest number of advantages and the minimum of defects. No matter how completely the engineer may achieve his task, the sum of his efforts is certain to meet with criticism, as a result of subsequently acquired knowledge.

Surveying in tropical climes is attended ith another factor which is not encount- red in more temperate regions. The ecided route or "location" is indicated y a row of pegs, spaced 100 feet apart— he length of a chain—down the centre of

MONTHLY PAY-DAY IN CAMP ON THE GOLD COAST RAILWAY.

he narrow survey cleavage through the scrub. These pegs indicate the centre of he track. At regular intervals they are supplemented on one side or the other by nother stake, known as a "bench mark," on which is indicated the altitude at that particular point. When it came to setting out these indispensable pegs in West Africa the engineer was confronted with the possibility of indulging unwittingly in a plan of re-afforestation. The stakes being cut from green wood invariably started to sprout after he had moved on. Then, as the survey line became obliterated in a very short space of time, owing to the amazingly rapid growth of the scrub, lively interludes and waste of time were encountered occasionally in searching for the location pegs by the constructional armies. When a nude stick planted by the surveyor has grown into a fully-fledged tree by the time the railway builder arrives, identification is by no means easy. Accordingly whenever a bench or location mark of importance had to be indicated the surveyor utilised something devoid of sprouting propensities. This generally assumed the form of a small block of concrete, sunk into the ground, from the centre of which projected a few feet of iron barrel. Such an expedient, while highly effective, has to be used but sparingly when one has to move rapidly through a dense country and when the only available transport facilities are the heads of natives!

The right-of-way is somewhat of more imposing width on the Gold Coast than generally is allocated for this purpose. This is essential to protect the track and

the telegraph wires from the destructive effects of windfalls. Some of the trees indigenous to this country are of huge proportions, ranging between 20 and 30 feet at the butt, and running to a height of 140 feet or more. Owing to the exceedingly wet character of the climate, the trees, generally speaking, are of little or no commercial value, being for the most part "soft." Pulping would appear to be their only possible commercial use. In fact this should offer a great attraction, seeing that British manufacturers are compelled to go two or three thousand miles afield for their supplies of raw material in the paper-making industry.

The Tree Problem.

While many of the larger trees are somewhat hollow and brittle, being analogous in this respect to the Canadian cottonwood, others are solid through the butt. Such a tree offers a pretty problem in its removal from the right-of-way, two or three days' continuous labour being required to bring it to the ground. In clearing operations natives were used almost exclusively, and although hand-felling with primitive tools may seem to lack expedition, in this instance the native was found to be more efficient, reliable, and cheaper than the much-vaunted modern methods. As these large trees averaged about twenty to the acre of right-of-way, and about 40 acres per mile had to be cleaned of all vegetation, this initial task in itself was a stupendous undertaking.

The Fire Remedy.

The felling of the trees and the cutting of the luxuriant undergrowth was only one, and the easiest, half of the work. When brought to the ground the vegetation had to be destroyed, as it was useless for constructional purposes. The large trees were split, hacked to pieces, piled and fired, which, owing to the wet climate and the wood being green, occupied time. Then came reckoning with the stump. As with the majority of trees growing in a wet region, and where there is a thick upper layer of decaying vegetable matter, the roots do not thrust themselves very deeply into the subsoil, but rather radiate in all directions along the surface. The usual method of treating these obstacles was to dig around the stump, severing the roots, and then to haul the mass to one side by the aid of rope and tackle to be burned in due course. Though progress was somewhat slow under these conditions, it was preferable to blasting the stumps, as it enabled native labour to be used, whereas expert and highly paid skill would have been necessary.

Windfall Dangers.

Although the swathe through the forest is 300 feet wide, the windfall obstruction of the railway is not eliminated entirely. Indeed, the interruptions from this cause upon the Gold Coast number about two hundred per annum; falling trees constitute the worst foe against which the management is pitted. The tall giants, owing to indifferent root-hold, are brought down very easily by a high wind, and as those on the edge of the clearing naturally lean towards the light, ninety-nine times out of a hundred they topple across the metals.

The Ever-encroaching Vegetation.

As the Gold Coast, from its hot, moist climate, is virtually a gigantic greenhouse, the undergrowth thrives amazingly. So much so that it is necessary to cut it back about twice a year; otherwise the permanent way runs the risk of being blotted out within a very short space of time. Thus the expense of clearing does not end with the initial operation; maintenance of the open space through the jungle is unavoidably expensive; in fact it represents a prominent item in the working costs.

As a rule when such a country is opened up by railway, a pioneer line is laid. Expense is kept down to the lowest

possible amount, the engineers following the path of least resistance, reducing earthworks to the minimum as well as disregarding the elements of curvature and grade. Then, as the railway settles down and the traffic grows, elaborate overhauling is taken in hand and the line is rebuilt practically. This policy has been found to be the most successful and remunerative in the United States, Canada and Australia, but it has its drawbacks; re-aligning always is expensive, as I demonstrate in a subsequent chapter.

A Wise Policy.

In the case of the Gold Coast Railway the guiding principle was "First cost: last cost." True it made the bill for construction somewhat heavy, but the wisdom of the policy has been justified completely by results. No grades exceeding 1 in 50 or curves of a less radius than 330 feet were permitted. Some heavy earthworks became requisite at places, while some of the embankments are of large proportions. The rails, weighing 50 lb. per yard, are laid upon pressed steel sleepers—wood was useless—while there is a complete absence of timber trestles or bridges from one end of the line to the other.

Although a high-class railway was laid down the constructional costs were reduced appreciably by exclusive resort to native labour and methods. One searched the grade in vain for steam shovels and other heavy and expensive mechanical appliances familiar to similar works in other parts of the world—all because the negro and his crude ways and means of doing things were found to be quicker, better, and cheaper. Nor was the spoil removed from this cutting to build up that embankment, as is the invariable rule. The former was thrown to one side, while the material required to fill a depression was taken from an adjacent ballast, or "borrow" pit.

The engineers were handicapped seriously by being compelled to carry every ounce of material required for the railway from the railhead, whence it was brought by train to the point of construction upon the heads of natives. On one occasion the engineer was describing the methods which had been adopted to a party of interested gentlemen, among whom was an American. The latter was familiar with the procedure followed by railway builders in his own country, and that human heads should be utilised for transport purposes perplexed him keenly. He reflected for a few seconds, and then, determined to solve what to him was a quaint puzzle, he fired the inevitable "Why?"

"A Gol-durned Country."

"Oh! Because there was no other way!" was the retort.

"What?" ejaculated the astonished American. "Weren't there any animals—horses, mules or oxen?"

"No!" retorted the engineer blandly. "Only snakes and mosquitoes!"

The American was nonplussed, but he dismissed the Gold Coast as being a "Gol-durned country."

Subsidences and Wash-outs.

The disadvantage of building the railway from one end only was that as rapidly as an embankment was raised the rails had to be laid over it, no interval being permitted to allow settlement to take place. Inasmuch as the earthworks were built on treacherous ground, although the depressions were drained as far as practicable, and the ballast was little better than loam or silt, subsidences were frequent. When the wet season set in the new earthworks suffered heavily at places, the soft soil either being washed away, packing tightly, or spreading, thereby producing ominous "sink holes." Further dumping and ballasting had to be carried out, the metals being lifted with jacks as the ballast was tamped beneath. To make matters worse, as the line approached the gold district, the mines, instead of shipping their material over the route followed

before the coming of the railway, landed it at Sekondi and dispatched it to the railhead, whence it was transported overland. The result was that the railhead not only became choked with railway constructional material for the line, but also with goods for the mines.

TESTING A BRIDGE ON THE GOLD COAST RAILWAY.

As the railway penetrated the jungle the labour question became somewhat acute. The forest is practically tenantless. White labour was impossible, even if it had been available, from motives of cost and the susceptibility of the white man to the dreaded indigenous diseases. So a native recruiting campaign was inaugurated. The District Commissioners of the British West African colonies circulated appeals for labourers throughout their respective territories. At first the harvest was not very inspiring, but as the negroes learned that the White Man's money was certain and regular, and that fair treatment was meted out, while good food was provided, they accepted the opportunity to supplement their means of existence. The wages from the civilised point of view certainly were not princely, averaging a shilling per day with all found, but the native was perfectly satisfied. When work was in full swing 16,000 natives found steady employment, 12,000 of whom were brought in from Lagos. Upon the completion of the railway this vast army, or those who preferred, were restored to their homes. The natives proved to be highly intelligent, and for the most part developed into good workmen. They were accommodated in large camps, which assumed such proportions, with serried rows of well-thatched huts, as to suggest prosperous native villages.

The negroes proved tractable and, on the whole, were not so lazy as those found in other parts of the continent. Squads of natives were drilled to act as police, and they kept law and order in a perfect manner. Once a month the whole toiling population lined up round the engineer's

hut, gaily bedecked and dressed as if for a fête. In the hut was a table and one or two engineers, before whom the natives passed in a regular, well-ordered queue to draw the reward for their labours in the coin of the realm.

The cost of construction was inflated very appreciably owing to the distance of the railway from the purchasing markets. Every ounce of provisions, building material, and other necessaries had to be brought from England. The one item of freight was exceedingly heavy, many articles by the time they were landed at Sekondi having increased seven- or eight-fold in price, and this handicap was felt most seriously in connection with such commodities as matches, sugar, soap, and so forth.

A vessel laden with supplies put out from Liverpool once every month while work was in progress. The commissariat was a heavy responsibility, bearing in mind the large army of toilers that had to be fed. But the arrangements were laid so carefully that no apprehensions ever arose under this heading, although now and again everything went awry from some unforeseen mishap, such as the total wreck of a supply steamer off the West African coast. Losses in landing at Sekondi, owing to the absence of harbour facilities, were considerable, but this was a drawback which could not be compassed. These misfortunes, however, affected the progress of the railway more adversely than the labourers. Several weeks' delay ensued while duplicate orders of the lost material were being fulfilled at home and shipped.

As the railway was approaching Tarkwa in 1899 the first serious indication of native

A CONSTANT MENACE TO SECTIONS OF THE GOLD COAST RAILWAY.
A wash-out in the Achemotah Valley.

hostility to the white invasion became manifest. In April, 1900, King Prempeh rose in rebellion. The disaffection spread like wildfire. The engineers working on the advance works, or engaged in survey-revision work, were deserted, while the negroes imported into the country for the enterprise, becoming nervous, retreated towards the coast or the big camps. The survey engineers, concluding that the rising was somewhat trivial, stuck to their ground, only to retreat when they learned the true significance of the outbreak, or to be driven in. Work at the railhead was thrown all sixes and sevens. Importation of labourers from the adjacent territories was stopped summarily, the government fearing that upon being landed the recruits might go over to the enemy. The natives already in employment were commandeered by the military authorities to act as carriers for the troops selected for the forced march to Coomassie to quell the outbreak. There was a complete disorganisation, and everything was brought to a standstill.

The Ashanti Rebellion.

In 1899, prior to the outbreak of the war, Mr. Frederic Shelford, who had taken over the reins of railway building operations upon the retirement of his father, and who inherited the pioneer's enthusiasm in a vigorous railway expansion policy for the Gold Coast, matured plans for continuing northwards from Tarkwa to Coomassie. Prospectors scouring the country north of the existing gold district had discovered further deposits of the yellow metal. Mr. Shelford, having been on the spot, recognised the extent of this later discovery, as well as the possibilities of developing other resources which were lying dormant. Thus the moment was opportune for extension, and he communicated his views to the Right Honourable Joseph Chamberlain, who was then Colonial Secretary. The Minister was sympathetic, but a counter-proposal had been advanced by Sir William Maxwell, the Governor of the Gold Coast, for the building of a line from Accra, the English capital, to Coomassie. Mr. Chamberlain agreed that a railway should be built to the Ashanti stronghold, though he suggested that surveys should be made both from Accra and Tarkwa respectively to Coomassie. He promised, whichever route was the more favourable, that construction should be undertaken without delay, as he was fully alive to the urgent necessity of the enterprise.

The Gold Boom.

The survey between Tarkwa and Coomassie was undertaken by Mr. Frederic Shelford personally, and he started out with one assistant and fifty native porters. Progress was found to be even more difficult than it had been between the coast and Tarkwa. It was an endless tramp through a succession of evil swamps and dense jungle, where the rainfall is terrific, 4 or 5 inches of water being by no means uncommon in a single "tropical shower." There was not a single native track to help Mr. Shelford. His compass was his sole guide, and he hacked and hewed his path foot by foot. In order that he should not be impeded in his reconnaissance, the personal impedimenta had been reduced to the scantiest necessities. No camp outfit was carried beyond a few utensils for the preparation of the food, and to filter and boil the drinking water. At the end of the day a small clearing a few feet in circumference was made, to allow the camp, such as it was, to be pitched, while the ground, with its damp pile of rotting vegetation, constituted their couch.

Extension to Coomassie.

This expedition also met with misfortune. Mr. Shelford's assistant was struck down by black-water fever before they had penetrated far. While this reconnaissance was being driven, the Ashanti War broke out, although the party were

ignorant of the fact. Mr. Shelford plodded forward, cutting, hacking, and hewing his narrow way through the forbidding and now hostile country. Fortunately for him, he escaped the vengeance of the rebellious natives, who evidently had massed at Coomassie. The result was that when he at last gained Prempeh's capital he was surprised to find the English troops in possession. He himself was the first Englishman to enter the stronghold from Sekondi. His northward dash from Tarkwa, spying out the lay of the country for the railway, had taken about three weeks. The survey thus obtained was compared with that run *via* Accra to Coomassie, and, being found preferable from all points of view, it received official acceptance.

THE ARRIVAL OF THE FIRST LOCOMOTIVE IN COOMASSIE.

The overthrow of the Ashanti king and the pacification of the country after its addition to the Gold Coast enabled the construction of the railway to be resumed, and in May, 1901, Tarkwa was linked to the coast. Then the development of the mines went forward with a rush. In one stroke the transportation charges were reduced from £40 to £5 per ton, and the effect was felt immediately. The heaviest machinery now could be brought up with ease and installed. Before many months had elapsed the heart of the hinterland was a throbbing hive of activity.

There was no pause in railway-building operations. The Sekondi-Tarkwa-Coomassie survey having met with approval, the advance to the former capital of Ashanti was commenced in June, 1901. Eighteen months later the railway had penetrated to Obuassi, 86 miles beyond Tarkwa, having advanced at the rate of $4\frac{3}{4}$ miles per month, which, bearing in mind the heavy clearing and earthworks which were necessary, constituted a striking performance. In September, 1903, the objective was reached—Coomassie was brought into railway communication with Sekondi on the coast.

So far as bridges are concerned, heavy works of this character were not found

necessary. The most important, perhaps, is the Ancobra Bridge, on the branch line, 19 miles in length, which runs from Tarkwa to Prestea. This bridge has four spans—two approach each of 45 feet, one of 90 feet, and a central span of 180 feet respectively. The erection of the main big span was carried out on the overhang or cantilever system, the spans on either side being used as anchorages. The bridge is of the half-through, or "trough" type, supported upon concrete piers 40 feet in height. The next largest bridge is that across the Huni River, the main span of which has a length of 150 feet. All the smaller bridges are of a permanent character, with concrete piers and abutments, and steel plate girders.

The Bridges.

The Rolling Stock.

The rolling stock is of the latest type. The locomotives follow the British design with American cow-catcher and head-light. The most powerful engines are of the 4–8–0 class, and these handle the traffic between Sekondi and Coomassie. To protect the European drivers from the sun and rain the roomy cab is fitted with a double roof. The coaches are of the end-corridor pattern, upholstered according to the class.

It comes as a surprise to the stranger to the Gold Coast, who is familiar with the railway travelling comforts of home, to find cars fitted with kitchens, sleeping-berths, baths, and other luxuries traversing a country which only a little more than a decade ago was "dark" in the fullest interpretation of the word. His astonishment is complete when he finds that he can assuage his thirst upon the "Coomassie Limited" with a bottle of Bass for sixpence, or a whisky-and-soda for ninepence! Truly the advance of civilisation is rapid.

What the Railway has Done.

The metamorphosis of West Africa constitutes one of the most remarkable incidents in railway history. In few other countries where maps were non-existent, where the rainfall averages as much in a month as during a year in Great Britain, where the forest was untrodden, and where malaria reigned supreme, has so sudden and complete a change been wrought in such a short space of time. In 1897 Sekondi was a handful of straggling mud huts dotting the shore. To-day it is a busy terminal port with sidings, substantial administration buildings, a hospital, and other attributes to a busy growing centre. In August, 1898, the engineers commenced to carve their way through the forest, and although work was interrupted by scarcity of labour, a harassing climate, and the Ashanti War, the first 40 miles to Tarkwa were completed in May, 1901—a matter of thirty-three months. The overthrow of King Prempeh and the resultant pacification of the country enabled construction to go forward more rapidly on the northern extension, Obuassi being reached in seventeen months, while the last lap of 44 miles into Coomassie was finished in seven months—an average advance of 6·3 miles per month. On the Tarkwa-Obuassi section rail-laying reached 12 miles per month, which conveys some idea of the energy with which the work was prosecuted when untrammelled.

This achievement is all the more remarkable when the difficulties concerning the personnel are borne in mind. The changes in the staff were everlasting, owing to sickness. During the progress of the work no fewer than ten chief engineers were appointed in turn.

Does the line pay? Well, whereas in 1905 the net receipts were £51,000, in 1911 the net earnings were £183,798. Such a result proves conclusively that the £1,857,237 sunk in the railway development of the Gold Coast is proving a highly profitable investment, which is certain to increase as the illimitable resources of the country are opened up.

THE HURLEY TRACK-LAYER AT WORK.
This machine lays and spaces the sleepers on the ground and sets the rails.

The Labour- and Time-Saving Track-Layer and its Work

A WONDERFUL MACHINE FOR LAYING RAILWAYS ALONG GREAT DISTANCES

ONE of the most interesting developments, from the mechanical point of view, has been the perfection of methods for laying the metals. So far as Great Britain is concerned there is no need to depart from the practice of laying sleepers and rails which has obtained since railways came into being. Mechanical systems never would pay here, because the day of big railway undertakings seems to have drawn to a close. The mechanical track-layer, to prove its value, demands a clear run of several score miles; then its force is demonstrated somewhat powerfully.

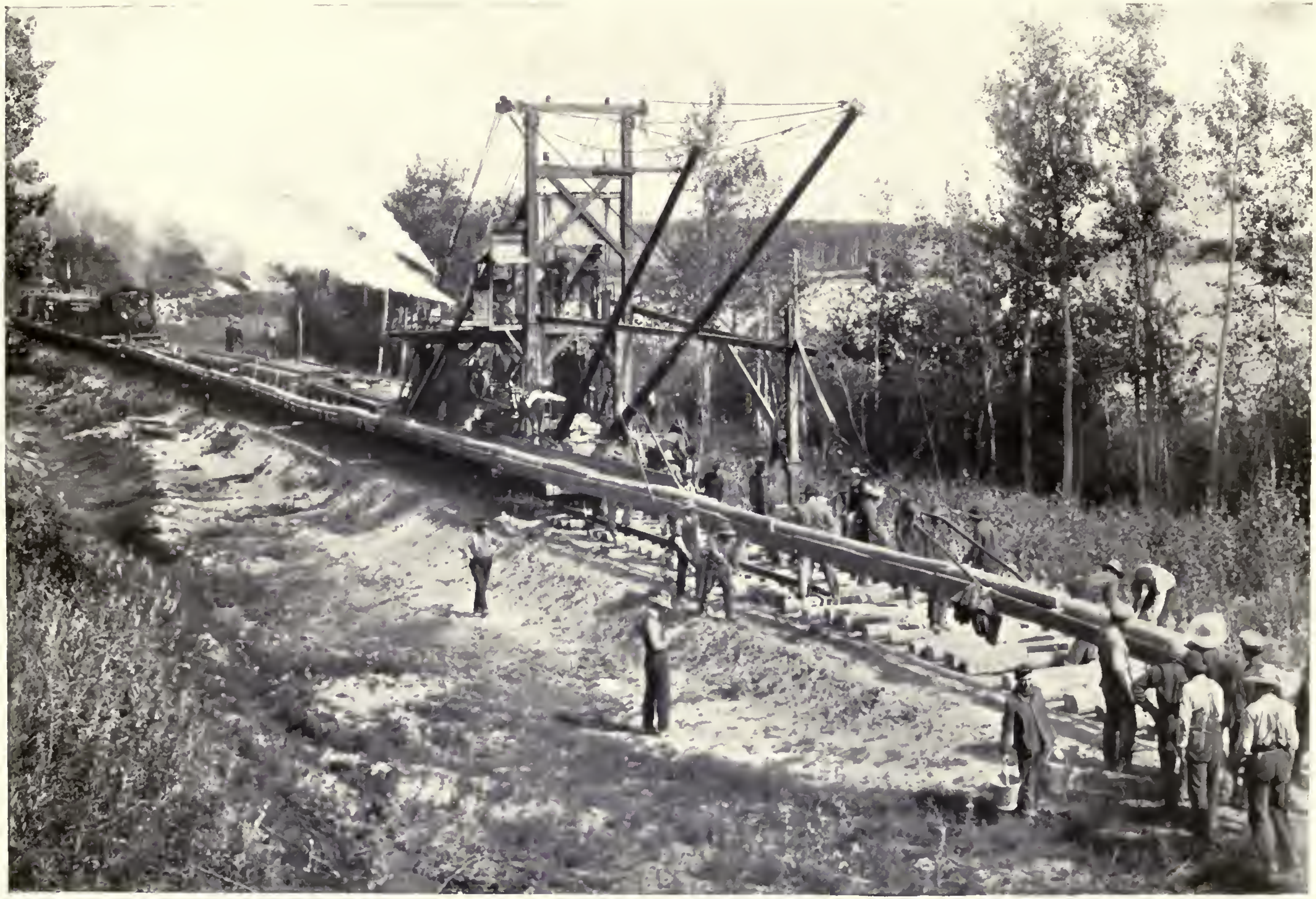
In order to obtain the most telling expressions of its utility one must visit Canada and the United States, where railway expansion upon a huge scale is in progress. Hand labour never could cope with this situation; metals and sleepers are weighty to handle. So of necessity the mechanical system was evolved.

The track-layer is mistitled somewhat, according to Old World interpretations of railway building. It does not lay the track lock, stock, and barrel complete for service—it simply dumps the sleepers on the ground and places the rails upon them. The two are then temporarily gauged up and secured together. It is merely a skeleton track, sufficient for the movement of constructional trains and material to the front. The track has to be completed by hand in the usual manner before it is fitted for ordinary service. Still, by laying the metals in this manner the saving in human muscle, physical exertion, and labour in the first instance is very appreciable, because throwing about heavy baulks of timber measuring 8 feet in length, by 8 inches wide and 6 inches deep, and 33-feet lengths of steel weighing maybe 90 lb. and 100 lb. per yard, is hard, slow work. At the same time it enables the glittering ribbon of steel to advance more rapidly through the country than is possible under manual methods; the railhead is kept in closer touch with actual work upon the grade.

Photograph by permission of the Grand Trunk Pacific Railway.

THE ADVANCE OF THE TRACK-LAYER, SHOWING THE GRADE AHEAD.

Although the track-layer may differ in many details of construction, the fundamental design and principles of operation are common, except in one instance, which I shall describe later. It is a cumbrous, lumbering piece of machinery carried on a flat car. At its forward end is a gantry or gallows-like structure, from the base of which project two booms, one on each side, whence the rails are handled. The deck of the car carries the steam plant for



Photograph by permission of the Grand Trunk Pacific Railway.

LAYING THE RAILS: SHOWING THE TROUGH FOR CONVEYING SLEEPERS AT THE SIDE.

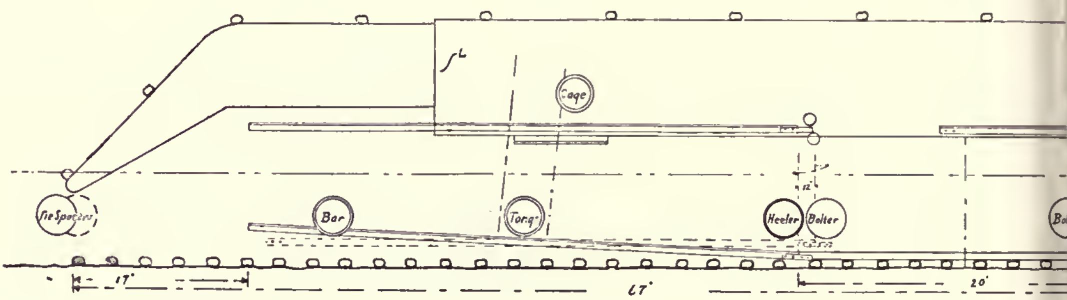
With this machine 126 miles were laid in 26 days.

the supply of power to the machinery, while on an upper platform are stationed two men who carry out the delicate task of setting the rails in position. In a crow's nest, immediately beside these men, and commanding a complete uninterrupted view of the whole operations in front, sits the man in charge of the track-laying gang.

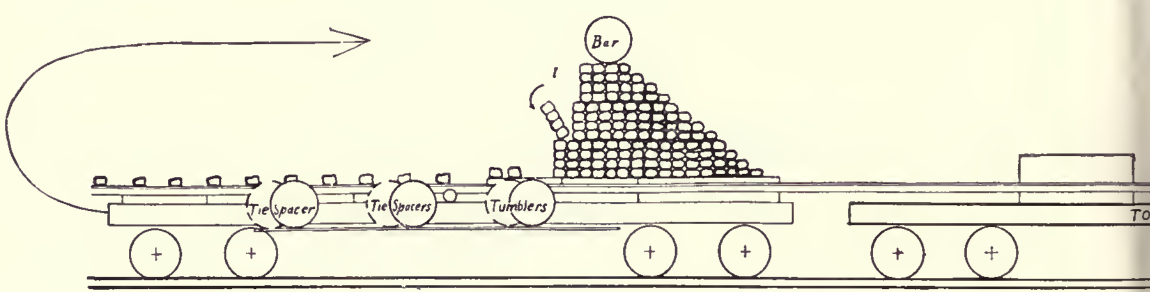
Immediately behind the track-layer come the trucks piled up with the steel rails, and an adequate supply of fish-plates. Then follows the engine, and lastly the deck cars stacked high with the sleepers. The locomotive thus is placed in the centre of the equipment. Extending along one side of the train, from end to end, is a big wooden trough, through which the sleepers are conveyed from the trucks to the grade beyond. This trough projects some 40 feet or more beyond the track-layer. Thus the sleepers are shot on the ground more than a full rail length ahead. The bottom of this trough is fitted with rollers armed with spikes, which, in revolving, grip the under side of the sleeper and propel it forward. The baulks are hurled through the trough in a continuous stream, the supply to the forward gang being governed entirely by the rate of the feed from the trucks into the conveyor.

The operation is very simple. The constructional engineer has left the grade carried to formation level; its surface is clean, level, and clear. Down the centre of this pathway runs a row of pegs corresponding to the location stakes of the surveyor. As these pegs coincide with the centre line between the rails, the foreman casts off his distance on one side and sets his gauge line.

The track-layer lumbers up to the end of the completed track under the pushing effort of the locomotive, and then work commences. The track-laying gang is distributed over the train and the grade in front. The conveyor rollers rattle and



L.—Vertical shaft which allows truss to swing on curves.



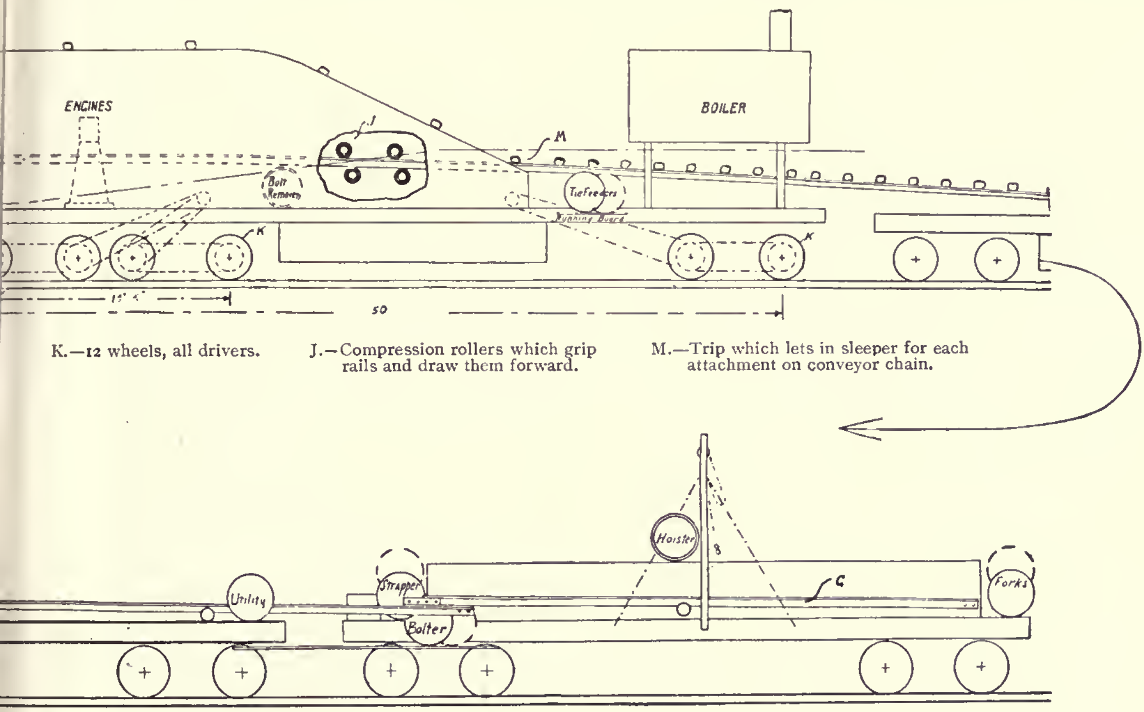
SLEEPER CAR SECTION.

I.—Sleepers rolled on to moving rails and carried forward to the machine.

THE HURLEY TRACK-LAYER

clank; the men on the first sleeper truck behind pitch the baulks into the trough as fast as they can. With an ear-splitting din the timbers are hurried forward, and are disgorged upon the grade ahead. As rapidly as they fall out of the trough they are prised, pulled, pushed, and tugged into position, spaced the requisite distance apart, while care is perfunctorily carried out, everything being trued up hastily.

Directly a rail on each side has been laid the machine crawls forward. The extent of this intermittent advance varies according to whether the joints in the rails are in line or broken. In the first instance progress will be the length of a rail; in the second case only about half that dis-



RAIL CAR SECTION.

G.—Position of rail after being lowered on to roller.

SHOWN DIAGRAMMATICALLY.

seen that one end toes the gauge line at the side.

Meanwhile the men on the trucks laden with the rails temporarily attach a pair of fish-plates to one end of a 33-feet length of steel, which is caught up and whisked to the front. It is lowered steadily, the free end drops between the two fish-plates on the last rail laid, bolts are slipped through to connect up, the gauge is struck, and with a few deft swings of the heavy sledges the gangers drive a spike here and there to clinch the metal to the sleepers below. In the first instance the work is tance. The noise is deafening. The screech of steam mingles with the rumbling and growling of the sleepers as they come bumping along the wooden conveyor trough. There is the ring of steel as the rails are swung out and lowered, and the clash of metal as the heavy sledges are swung to drive home the spikes and bolts. Above all may be heard the raucous shouts and orders of the man in the crow's nest, and the babble of the 120 odd men, probably of half a dozen nationalities, shouting with the force of megaphones to make themselves heard.

Under favourable conditions the metals can be laid at an average rate of two miles per day. When the going has been particularly advantageous, and a full gang of expert men has been available, the railway has crept forward between four and five miles between sunrise and sunset. There is a friendly rivalry among the crews, and if a chance presents itself, they let themselves go with infinite zest in the effort to create a day's record. But the track so laid is extremely crude—a skeleton line in the fullest sense of the word, and little better than that laid down by the constructional armies for the movement of their ballast wagons and material. When the track-layer has passed and the strip of white level grade has received its steel embellishment, the line looks as if it had been twisted and buckled by a seismic disturbance, or had writhed under extreme expansion set up by an abnormally hot summer's day.

Rate of Advance.

Hard on the heels of the track-layer come the aligning and levelling gangs. They straighten the kinks in the ribbon of steel, correct all the sags by lifting and packing ballast under the sleepers, and complete the trueing and bolting up, as well as the spiking to every sleeper. Over this skeleton track, trains may move forward at slow speed—say up to six or eight miles an hour. As the rails are laid on the subgrade, and ballasting is not carried out until later, very little effort is required to throw the track out of gauge. I recall one journey I made on the engine of a construction train shortly after the metals had been laid. Three times in as many miles the engine dropped between the metals owing to the spreading of the rails. But the construction train expects such interludes, and, in anticipation, carries a goodly supply of tackle aboard in the form of powerful jacks, whereby the engine is lifted back again without very much trouble or serious delay. Then the train is backed a few feet, and the men on board fix up the road by bringing the rails into gauge so that the train may pass.

The foregoing type of track-layer has been that in general use for many years, and has given general satisfaction. From time to time the details are improved, for the purpose of facilitating the avowed task of the machine. One man who had completed such an improvement came to an unfortunate end. He was on the track-layer, giving instructions, when he slipped. Before he was able to recover himself he was on his back in the sleeper conveyor, was caught by the spikes on the rollers, and was ground to death by the ever-moving stream of timbers before he could be extricated.

An Unfortunate Inventor.

Recently a distinct improvement has been effected upon the foregoing type of machine. The latter does not lay the track, it merely delivers the material for manual power to set in position. Still, when it is remembered that, upon a modern railway of standard gauge, the aggregate of metal and wood which has to be handled represents a matter of 350 tons per mile, it will be acknowledged that it constitutes a very helpful auxiliary.

The latest machine, known as the Hurley Track-layer, better justifies its name, inasmuch as it automatically lays the sleepers and rails in position on the ground. Manual effort is reduced to the minimum. The whole working principle of the Hurley apparatus differs from that of the ordinary appliance. Instead of moving forward intermittently a matter of 16 feet or so at a time, it travels constantly—very slowly, it is true—as the drive is transmitted to the wheels through reducing gear, the speed being designed so as to ensure continuity of track-laying and progress simultaneously. A locomotive for pushing purposes is not required—the plant is self-contained, and a distinct working unit.

The Hurley Track-layer.

The travelling speed varies from 12 to 40 feet per minute, far slower than a locomotive could move, and at this speed it can haul a train, ranging up to thirty laden cars, according to the grade.

The train is completed with the cars laden with rails. Instead of a conveyor trough, two rollers are laid on each side, and at the respective ends, of each car.

The *modus operandi* is very simple.

Photograph by permission of the Grand Trunk Pacific Railway.

THE "LIFTING" GANG TRUE-ING, LIFTING AND LEVELLING RAILS AND COMPLETING SPIKING TO SLEEPERS.

The mechanical car carries a pair of reversible stationary engines which suffice to actuate the machinery and to drive the train. From this car projects a huge truss, which overhangs the grade, whereby the sleepers and rails are delivered to the ground. Immediately behind the engine car is the fuel and water supply truck. This can be detached from the track-layer and hauled back to the loading point to be replenished at the end of the day's work. Then follow the trucks loaded with the sleepers, which are stacked transversely.

Work commences at the first car of rails behind the track-layer, the rails being stacked in the form of a pyramid on the flat truck. This latter is fitted with a portable frame, or gantry, the legs of which drop into pockets in the frame of the vehicle. This frame carries an overhead friction hoist. The rails are lifted one by one from the stack and lowered on to the rollers, where they are connected together by slipping a couple of bolts through the connecting fish-plates. The result is that the rails move forward in a continuous

length to the track-layer, travelling over the rollers at the side. When the first truck has been exhausted of rails, the gantry is lifted out of its pockets and transferred to the succeeding vehicle, and so on until the whole of the rails have been sent forward.

As the rails move along the rollers they pass over the trucks laden with the sleepers, but underneath the two sides of the stack, and in such a way as to be clear of the latter. On each of these trucks are piled from 375 to 500 baulks, according to the length of the vehicle. As the rails travel forward, men stationed on the wagons roll the sleepers on to them, so that the rails really become a conveyor. Other members of the crew, standing on side planks, space the sleepers upon the moving track the same intervals apart as they will occupy when laid on the ground. Thus one sees a length of inverted track moving constantly towards the front of the train.

How the Sleepers are Placed.

When the moving rails with their sleepers reach the engine car, the two become separated, the rails passing between friction rollers, which supply the forward moving effort to the rails, while the sleepers are sent upwards, still the allotted distance apart, over the top of the machine, along the upper side of the truss, and are delivered on to the ground by means of a conveyor. As the track-layer is moving forward constantly, and owing to the truss overhanging the grade ahead, the sleepers are tumbled exactly into their requisite position, and the correct distance apart upon the ground. All that has to be done is to see that they toe the gauge line, men armed with tongs effecting this adjustment without undue effort. As the truss gives a clearance of 8 feet clear above the roadbed, there is ample space for the men to work beneath.

How the Rails are Laid.

The rails, after parting company with their sleepers, and being drawn through the friction rollers, are detached. The fish-plate bolt is withdrawn from one end, while the other is loosened, so that the two fish-plates are left on the rear end of each rail. This task completed, the rail is drawn forward by means of speed rollers, and passes along the lower edge of the truss to a point about 20 feet ahead of the front of the car. Here it is grabbed by specially fashioned tongs, and lowered until the rear end drags along the rail previously laid. It is held suspended until it has come within some 12 inches of the end of the rail on the ground. A man then swings the suspended rail forward until the attached fish-plates drop over the end of the previous rail, the pressing tendency of the swinging length of metal being sufficient to keep the two ends together until a clamp, which holds both fish-plates and rails together, is applied, when the tongs are released. A bolt is slipped in to join the new to the previous rail, the clamp is released, the forward end of the rail is lowered upon the sleepers, while bolting-up and spiking here and there are accomplished during the interval the track-layer is moving forward 20 feet. Thus the machine moves on to the new length of metal without a pause.

The machine section of the train is a weighty mass, turning the scale at some 65 tons, but this weight is distributed over a wheel-base of some 50 feet. As the Hurley track-layer completes the whole operation without the assistance of a locomotive, a saving from £5 to £8 per day under this heading alone is effected, while as a smaller crew is sufficient to handle the complete equipment than in the case of the ordinary type of track-layer, the machine is both money- and labour-saving.

Some remarkable achievements have been placed on record with this machine. A force of 42 men can lay 2 miles of track a day, while a small squad of 18 hands

can complete $1\frac{1}{4}$ miles in the same time. With an expert full crew, 1,800 feet of metals have been laid in an hour. Weather conditions do not affect the working speed, and even swampy ground can be crossed in safety, and without inflicting the slightest damage upon the road-bed, owing to the long wheel-base and distribution of weight. In Wisconsin 3,000 feet of track were laid in a couple of hours, notwithstanding the fact that during the greater part of this time a blinding snowstorm was raging.

The apparatus is just as effective upon curves as upon stretches of tangent track. The overhanging truss is able to swing to the curvature, owing to the construction of its front end, and the sleepers are deposited to the centre line upon the ground under all conditions. From the money-saving point of view its value is forcibly emphasised, judging from results achieved in building the Kansas City, Mexico and Orient Railway, where the engineer-in-chief estimates that the machine has saved him over £40 per mile, as compared with other methods of track-laying.

Subsequent to the passing of the track-layer the road has to be overhauled from time to time—ballasted, lifted—so as to bring it into the pink of condition for fast and heavy traffic. If the actual cost of construction is compared with the manual system practised in Great Britain and Europe generally, it is doubtful whether it shows any advantage, but it certainly offers a means of getting the metals down more quickly, so as to provide an improved and accelerated means of transporting material, and men for grading, to the front.

LAYING THE METALS AT THE RATE OF FIVE MILES A DAY.
The track-layer at work on the Chicago, Milwaukee and Puget Sound Railway.

THE TWO TYPES OF BOILERS READY FOR THE TEST AT THE TRIAL GROUNDS.

A Safety Locomotive Boiler

BOILER-BURSTS ARE COMPARATIVELY COMMON IN AMERICA. HERE IS DESCRIBED AN INTERESTING TEST OF THE EFFICIENCY OF A NEW FORM OF BOILER

FORTUNATELY for railway travellers and others in Great Britain, the explosion of the boiler of a railway engine is a very rare occurrence, owing to the skill and care devoted to construction and maintenance, as well as to the thoughtful management of those responsible for its operation. But the United States present a very vivid contrast in this respect. There, on the average, a railway engine blows up once a week, and this class of calamity accounts for a long list of killed and maimed, as well as damage to the tune of several hundreds of thousands of pounds to property per annum.

Investigation invariably tends to attribute these disasters to one of two causes—a defect in manufacture, or gross mismanagement. Of course, in a few instances, even the most searching examination fails to offer a reason for the accident, but such mysteries are few and far between. Taken on the whole it is the penalty of carelessness which has to be feared the most, and in the direction of controverting this danger little has been possible of accomplishment by the railway companies, seeing that it turns upon the human factor.

The ordinary type of locomotive boiler is safe and reliable so long as it is handled with due care and thoughtfulness. Otherwise disaster swift and sudden is encountered. If the level of the water in the boiler is permitted to fall to such an extent that the roof or " crown " of the fire-box becomes uncovered, an explosion is inevitable. The fierce heat of the fire raises the temperature of the uncovered metal to such a degree that it loses its strength, cannot withstand the pressure of the steam within, and is driven inwards.

A certain amount of resistance to this internal pressure of the steam is provided by securing the crown sheet of the fire-box to the outer shell of the boiler by means of radial stay-bolts. So long as the water level is kept above the danger limit this security is adequate and the fire-box is held to its shape against the steam pressure. On the other hand, if through negligence or by oversight the crown of the fire-box is exposed to the fire, the stay-bolts become impotent, and are torn through the sheet, which then collapses.

The Jacobs-Shupert Boiler.

Two American engineers, Messrs. Jacobs and Shupert, in the locomotive shops of the Atchison, Topeka and Santa Fé Railway Company, realising this weak feature of the ordinary boiler, endeavoured to design a type which would hold up against a low water level. After experimenting for several years they succeeded in their quest, and produced a boiler which is stronger and safer than those in general use. It was subjected to several tests and trials upon the railway, and, being found successful, has become widely adopted throughout the United States.

This Jacobs-Shupert boiler is built up in sections. The radial stay-bolts which hold the ordinary fire-box to shape are dispensed with entirely. Instead, there are a number of deep flanges, extending from the outer shell of the boiler to the inner shell of the fire-box. The shell of the latter is built up of a number of channel sections of arch shape, and these are riveted to the inside edges of the stay flanges. The adoption of the section secures exceedingly strong construction. Moreover, as the section is strongly riveted to the inner edges of the flanges, the crown sheet is able to withstand an enormous amount of pressure, which becomes distributed over a very great area before it can be wrenched free and driven in.

Interesting Experiments.

The inventors embarked upon a series of elaborate experiments to discover the behaviour of their boiler under low water conditions. Adjoining their Coatesville works in Pennsylvania an elaborate testing plant was set up in a field. The boilers were rigged up, charged with water, and then fired, the water being permitted to fall lower and lower until the crown of the fire-box was well exposed. Inasmuch as the boiler could not be stoked by a fireman in the usual manner, owing to the possibility of a blow-up, oil-fuel was used, being controlled from a safe distant point. In order to follow the falling level of the water as represented by the gauge, as well as to secure continuous readings of the steam pressure indicated upon its gauge, a bomb-proof shelter comprising a boiler laid on its side, and backed with baulks and earth, was erected some distance away for the accommodation of the observers. The readings were taken from this point by the aid of a telescope mounted on the roof of the bomb-proof shelter. Thus it was possible to follow the tests closely in perfect safety.

An Independent Test.

The numerous experiments made in this way fully confirmed the statements advanced by the inventors concerning the properties of their boiler, and the reduced liability, if not complete immunity, from accident ensured by the same when the fireman, through oversight or carelessness, permitted the water to fall somewhat low.

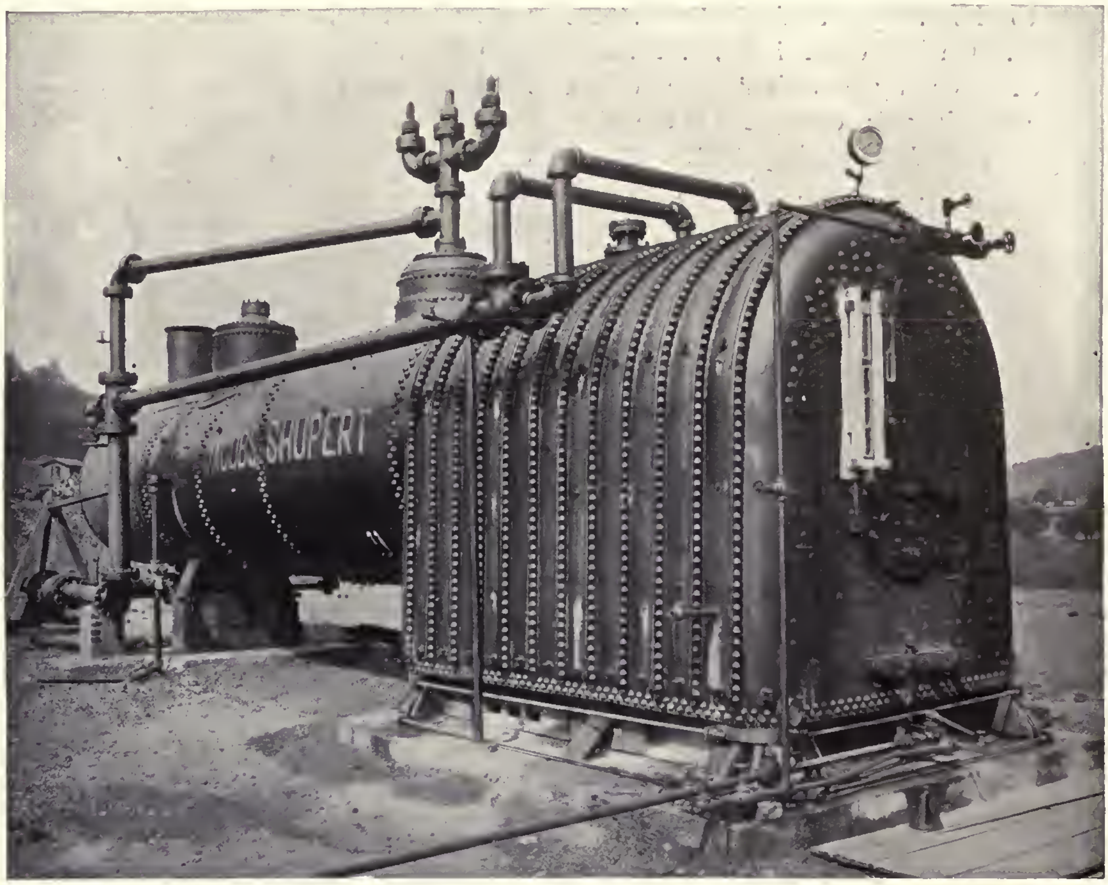
Finally, in order to secure an independent expert opinion, as well as comparative results, an interesting trial was carried out by Dr. W. F. M. Goss, Dean of the College of Engineering of the University of Illinois, who is probably the greatest authority upon this subject in America.

In carrying out this test it was not only decided to submit the Jacobs-Shupert boiler to an unprecedented gruelling, but also to ascertain how far it was proof

against explosion arising from low water conditions. Comparative results also were to be made with a view to ascertaining what the ordinary type of boiler could withstand in this connection, and also to determine whether, as had been maintained, a low water level was a positive cause of explosion.

For this purpose two full-sized locomotive boilers, such as are used for heavy express service, the one a Jacobs-Shupert and the other of the ordinary radial type, were set up in the experimental field. They were placed 50 feet apart, and the observer took up his position in the bomb-proof shelter placed 200 feet away. The fire-box end of each boiler faced the observer, and each carried a graduated water gauge and steam gauge, so mounted as to be seen readily through the telescope.

Each boiler was then connected to the feed water supply and set going until it reached the conditions which would prevail in actual express service. This was estimated to be equal to 1,400 horse-power, which would be sufficient to haul a fully loaded train at 60 miles an hour over a level road. At this juncture the feed water was cut off, but nothing else was touched.



EXTERIOR VIEW OF BOILER, WITH JACOBS-SHUPERT FIRE-BOX, IMMEDIATELY AFTER LOW WATER TESTS.

Note blistering of paint on outside of fire-box, due to intense heat.

The Jacobs-Shupert boiler was tried first. The observers followed the falling water for 55 minutes, by which time, according to the reading of the gauge, it had descended 25½ inches below the crown sheet. It may have fallen to a lower level, but this was the limit of the gauge glass. During the

BLOWING UP.

The ordinary boiler photographed at the instant the crown sheet collapsed. The Jacobs-Shupert boiler which passed the test successfully is alongside.

first twenty-seven minutes the steam gauge indicated a pressure ranging between 215 and 225 pounds. At the lapse of this period the pressure gradually decreased until only one of 50 pounds was indicated. The test was discontinued after 55 minutes, because the small amount of water remaining in the boiler did not evaporate fast enough to ensure the draught necessary to maintain the fire. No sign of any failure was observed, and when the boiler was examined there was adequate external evidence of the severity of the ordeal through which it had passed. The paint on the outside of the fire-box was blistered, and a good deal had peeled off. It was evident that the crown sheet of the fire-box must have been brought to a red-hot condition under the fierce heat of the fire, but there was not the slightest sign that it had been weakened in any way by this extreme temperature, and it was apparently as fit for service, if required, as before the test

The second boiler, of the radial stay type, was subjected to a test precisely similar to the foregoing in every respect, the feed water being cut off at an identical point. The steam gauge indicated a pressure varying from 200 to 233 pounds, and after it had been kept going for 23 minutes the water had fallen to a level 14½ inches below the crown sheet.

Then the crown sheet and the stays holding it in position had become heated to such a degree that they were wrenched apart, and the steam, at 228 pounds pressure, drove in the sheet. The steam rushed into the fire-box and there was a terrific explosion. Although the boiler weighed 40 tons, it was lifted off its seating, the fire-box was disrupted and fragments were blown in all directions. When examined, the boiler was found to be damaged so extensively as to require reconstruction.

This interesting test not only proved the efficiency of the salient features of the Jacobs-Shupert boiler, but also afforded convincing evidence that low water, with the overheating of the crown sheet, was a contingency beset with dire consequences, and probably is a common cause for a railway engine blowing up.

GENERAL VIEW OF THE TESTING GROUND.

Showing the Jacobs-Shupert boiler in position, shelter for observers, and display board whereon spectators at a distance could follow the variations in the water levels and steam pressures during the trials.

THE LARGEST INDIVIDUAL RAILWAY YARD IN THE WORLD.
A part of the 120 miles of sidings belonging to the C.P.R. at Winnipeg.

The Canadian Pacific Railway—I

THE STORY OF THE GREAT TRANSCONTINENTAL LINE WHICH IN PARTS COST £140,000 PER MILE

HALF a century ago the vast stretch of territory forming British North America was a heterogeneous collection of provinces, each of which virtually was a little kingdom in itself. Consequently there was an absolute lack of cohesive working: Canada presented a striking picture of a country divided against itself. And this was by no means the worst feature of the situation. On the Pacific seaboard was a flourishing colony, British Columbia, which not only was cut off from the other prosperous corners of Canada, but was also isolated from the Mother Country. In those days a journey to Vancouver was not to be undertaken lightly. If approached by water from England it involved a journey half-way round the world, and circuitous at that, since the vessel had to turn the southern extremity of the American Continent. On the other hand, the overland journey was just as forbidding, and quite as lengthy, because one had to toil afoot from the head of the Great Lakes over the prairies and across towering mountain ranges before the seaboard was gained.

British Columbia was handicapped by this isolation, so when a scheme was adumbrated to federate the various provinces the Pacific colony resolved to profit from co-operation. It would enter the confederation on one condition only—that it was brought into touch with Eastern Canada and the Atlantic seaboard by a railway.

The advocates of federation were staggered by this ultimatum. Why, west of the Great Lakes stretched a wilderness to the feet of the Rocky Mountains, and then as unkempt and as wild a stretch of rugged country to the Western Sea as could be conceived! The whole country was in the melting-pot, and although superhuman efforts were being made to weave the

tangled fabric together, here was one of the possible parties to the solution of a vexatious problem stipulating that a railway some 3,000 miles in length should be the price of its assistance. The terms were exacting. But British Columbia stood firm: a railway, or we stand aloof.

THE IMPERIAL LIMITED.

This C.P.R. Transcontinental Express runs direct between Montreal and Vancouver, 2,898 miles. The engine is changed about twenty times during the journey.

This was in 1871. Sir John Macdonald had formulated the confederation project, and he was determined to spare no effort to bring his pet idea to fruition. But this railway was a stumbling-block which he never had anticipated. However, he accepted the onerous conditions: promised that the line should be built, and went so far as to entice British Columbia into the compact by promising such railway communication by 1881. To prove the sincerity of his purpose a Government survey was started under Mr. (now Sir) Sandford Fleming, a railway pathfinder to the manner born.

Fleming rallied his forces and drove his way steadily across the full breadth of the continent. Fortunately he was not handicapped in any way by official red tape. He was instructed simply to discover the most practicable route for the transcontinental steel highway, and he set out to do it. The outlook was dispiriting, as it involved a toil through an unknown wilderness—the undisputed territory of

the Indians, Hudson Bay traders, and denizens of the forest.

There being no maps to guide him, young Fleming did the next best thing.

Fleming's First Survey.

He sought assistance from the Hudson Bay Company, whose men knew the western trails intimately, as they had to pack provisions overland to the Vancouver outpost.

It was a long trail which he drove from Montreal through Ontario's timber and rugged fastnesses to Winnipeg, then Fort Garry, the Hudson Bay trading post. He struck westwards to Edmonton, and a few miles beyond picked up Thompson's historic trek down the Athabasca River into the heart of the Rockies. Then he swung up the Miette River valley, crossed into British Columbia at the low altitude of 3,720 feet, dropped down the western slope of the Rockies, picked up the Fraser River, skirted Mount Robson, the twentieth century showpiece of the Dominion, gained Tête Jaune Cache, bore to the south-east, followed the valley of the Canoe River, came out at Kamloops, and then struck boldly over the well-trodden trail of Thompson and Simon Fraser to the sea.

In addition to this route ten other reconnaissances were run through the Rocky Mountains, in which quest Charles Moberly, a kindred born railway pathfinder, played a very prominent part. Yet when the results were compared it was found that the Fleming preliminary was the easiest and obvious path for the transcontinental steel highway. That was way back in 1872, and yet when I followed in his tracks forty years later I still found some of his location and bench marks buried in the dense Canadian undergrowth.

But Fleming's survey was not accepted. Thirty years were doomed to pass before its value became appreciated, when one new transcontinental railway actually followed his route through the mountain barrier. This is the Canadian Northern, as related in another chapter.

In the meantime the project had become the sport of party jealousy and strife, with the result that little was done.

British Columbia's Protest.

Although Sir John Macdonald had promised that the line should be completed by 1881, the end of 1879 saw the completion of only a paltry 713 miles. This procrastination provoked British Columbia. In blunt language it reminded the Dominion Government about its compact, and threatened drastic action if the bargain were not fulfilled instantly. Thereupon the Government swung to he opposite extreme. Dilatory tactics gave way to feverish haste. A syndicate comprising influential financial and technical interests expressed a willingness to take over the Government's responsibilities, and to fulfil the official obligations to the satisfaction of British Columbia on terms which were set out specifically.

The Federal Government, pressed by the Pacific province, was caught at a disadvantage.

The Syndicate's Terms.

The syndicate terms were exacting:—A subsidy of £5,000,000 sterling, together with a free grant of 25,000,000 acres of land, the gift of the right-of-way as well as space for stations and so forth ; the free entry of all material ; exemption from taxation ; and presentation, immune from all restrictions, of the 713 miles of line already completed. This was the irreducible minimum upon which the syndicate was prepared to do business. Time could not be wasted in further parleying, owing to the attitude of British Columbia, so the conditions were accepted, the Dominion Government merely stipulating in return that the line should be opened for traffic in the spring of 1891.

Work was commenced forthwith and went ahead with a swing until the funds to defray construction ran out. A crash appeared to be inevitable. The London market resolutely refused to advance a

RED SUCKER TUNNEL ON THE LAKE SUPERIOR SECTION OF THE CANADIAN PACIFIC RAILWAY.

single penny towards the enterprise. In desperation the eompany turned to the Dominion Government, whieh granted a loan of £6,000,000 upon what hostile erities deelared to be a lost eause.

Although probably never in the history of railways has a eonstruetional proposal been treated so liberally, possibly no enterprise so large ever experieneed so many vieissitudes. The eompany, eonfronted with the neeessity of maintaining an average advanee of 250 miles per year in order to meet the time limit, toiled unceasingly to keep things going by hook or by erook. Disputes were frequent; threats among the sub-eontraetors to "ehuek the job" were heard on every hand; work was seamped at plaees; while at other points the engineers were worried out of their wits over the eheap and speedy solution of exasperating teehnieal problems. Nor was the finaneial aspeet free from anxiety: harassing questions arose at every turn. The inside history of the Canadian Paeifie Railway never has been written, but when it is reeorded it will be found to reveal a persistent and eontinuous stubborn struggle against threatening disaster.

Fortunately men were found eapable of grappling with ominous situations. Among these were Sir William Van Horne on the engineering, and Lords Stratheona and Mountstephen on the finaneial sides. By prodigious effort they kept eonstruetion going, although at times they were somewhat downeast by the outlook, espeeially in regard to the "sinews of war." Labour, as usual, brought its manifold troubles. Railway expansion was aetive in the United States, where high pay was to be earned, so that Canada held out no tempting indueements. The majority of the graders

regarded work upon the Canadian enterprise in the light of a holiday, or a timely change of air and scenery. Many of the graders I know divided their time between the Canadian Pacific, Northern Pacific, and other American lines; they could not be tempted to stay upon one job more than a month or two on end.

The builders were forced to realise the magnitude of their task in the first stretch between Montreal and Port Arthur. Southern Ontario may be best described as a jumble of jagged mountains, rambling muskeg, water, and dense tangled forest. The location ran through the wildest stretches of all these physical conditions. A maximum gradient of 52·8 feet per mile and a maximum curvature of 6 degrees—955 feet radius—were laid down, and at times it was found difficult to keep within these restrictions. Between Montreal and Lake Superior the railway has to climb to an altitude of 950 feet above the level of the lake. The bleak, frowning, cliff-hemmed shore of this inland sea is picked up at Heron Bay, and hugged thence to Nepigon, a distance of 66 miles.

The surveyors were forced to take to the shore of the lake, and as a result a gallery had to be blasted out of the sombre granite, mica, schist, and black trap, a few feet above the water level, driving through the projecting lofty promontories and crossing the little bays, some of which were filled with the dislodged rock from the cuts and tunnels, while others were bridged. The rock was dense and put up a stern resistance: nothing but black powder and dynamite could cope with it. Under these circumstances it is not surprising that a mere stretch of 200 miles through Southern Ontario cost about £2,500,000, while at one or two places the cost ran as high as £140,000 per mile.

A LIBRARY-OBSERVATION CAR ON THE CANADIAN PACIFIC RAILWAY

CLEARING A SNOW-DRIFT ON
Heroic efforts are required during the winter to keep the line open for traffic. The rotary plough is

Photograph by permission of J. P. Forde, Esq., late Engineer-in-charge, Mountain Division of the C.P.R.

THE CANADIAN PACIFIC RAILWAY.

driven into the obstacle, which is thrown in a fountain high into the air, to fall some 60 feet to one side.

The region of Lake Superior has been described as the coldest and bleakest part of Canada, and the graders who had heard of this unsavoury reputation had occasion to remember that for once rumour did not lie. In fact, many of them, after the experience of a week or two, threw down their tools and departed to seek work in a more congenial clime. Camp comforts in those days were unknown, the commissariat was not so abundant or varied as the canning factories have made it to-day. The food in the winter was despairingly monotonous, and truly backwoods in character. "Mush"—oatmeal—pork and beans, bannock, and other concrete-like dainties formed the staple articles upon the menu, washed down with black tea, coarse coffee, and muddy cocoa without milk.

The Maddening Muskegs.

The sprawling muskegs of Southern Ontario were just as teasing and maddening as the hard rock. Every possible device for subjugating the bog was tried and found wanting. One muskeg, in particular, nearly drove the graders and engineers frantic. It swallowed rock and spoil by the thousands of tons, and timber corduroy by the hundreds of feet. Yet the embankment refused to become permanent. At last the engineers did succeed in getting a road; then the railway operators were given a taste of the bog's treachery and fickleness. It was just as if the permanent way had been laid upon a bank of resilient indiarubber. As the train passed over the road-bed it rose and fell in a series of little waves, while the rails themselves crept in all directions. A movement of 26 inches under a passing train was by no means uncommon. The gangers were driven almost to frenzy in their efforts to keep the metals to gauge. The bolts holding the fishplates snapped like matches. Every day fresh bolts were wanted somewhere or other within the worst section of a mile and a quarter, while surfacing and lining had to be carried out once a week. It was only by unremitting vigilance that derailments were prevented, until the engineer at last discovered a means of holding the metals in position by laying them on sleepers 40 feet in length, and connecting them with fish-plates 40 inches long, with slots cut in either rail at alternate sleepers.

From Port Arthur the line was driven through the heavily timbered and water-broken country of Western Ontario to Winnipeg. As this section of the journey was certain to be the most heavily taxed, from the traffic point of view, inasmuch as the whole of the grain and other produce would be conveyed from Winnipeg, the clearing house, to Eastern ports and the Great Lakes, special attention was devoted to the gradient and the substantial character of the permanent way, so that the line might not break down under the heavy traffic imposed.

[*In a subsequent chapter the course of the railway through the mountains is dealt with.*]

BRITAIN'S FAMOUS SIXTY-MINUTE FLYER, "THE SOUTHERN BELLE."

This train, comprising five to seven Pullman coaches, runs between London and Brighton, covering the 50½ miles in the hour.

By permission of L.B. & S.C.R.
THE AFTERNOON "SOUTHERN BELLE" EN ROUTE TO BRIGHTON.
Five-coach train drawn by 4-4-2 tank engine No. 28.

Two Famous Sixty-Minute "Flyers"

THE LONDON TO BRIGHTON "SOUTHERN BELLE" RUN COMPARED WITH THAT OF THE FAMOUS ATLANTIC CITY AND PHILADELPHIA EXPRESS

WHILE comparisons between train speeds attained in various countries invariably are interesting, as a rule it is almost impossible to discuss them fairly, owing to the difficulty of reducing the performances to a common basis. So many factors affect the situation, such as gradients, curvature, condition of the track, junctions, carrying capacity and weight of the trains, character of the service, and distance.

But there is one very interesting parallel affording comparisons to be drawn, seeing that the conditions are approximately equal. Both trains are scheduled to cover a similar distance in sixty minutes; the composition and weight of the trains are about the same; the permanent ways are alike and of the give-and-take order; both are non-stops; and both run from point to point in each direction. The one is in England, the other is in the United States; each is the crack train of its class in its respective country.

The English train is the "Southern

Belle," running between London and Brighton, which has earned justly the distinction of being the finest and most luxurious "sixty-minute flyer" in the United Kingdom. This train was inaugurated as the "Sunday Pullman Limited," to cover the $50\frac{1}{2}$ miles between Victoria and Brighton within the hour, in October, 1899. It proved an instant success, and although confined to Sundays, was always taxed to its utmost seating capacity. When certain widening and other improvements upon the line had been completed, the once-a-week flyer was converted into an everyday train, under the name of the "Southern Belle," the Pullman Company, Limited, taking the opportunity to introduce a train which, in point of palatial appointment and comfort, exceeded anything previously seen in these islands. The punctuality of this express constitutes one of the most striking features of the London, Brighton and South Coast Railway's long distance traffic, and very justly it has become known as the "clock-train."

THE BUFFET CAR "GROSVENOR" ON THE "SOUTHERN BELLE."
Luxurious appointment is the feature of this train: this car is furnished in the Adam style.

Its composition varies from five to seven Pullman coaches, according to the exigencies of the traffic. Each car measures 63 feet 10 inches in length, by 8 feet $8\frac{3}{4}$ inches in width, with a height of 13 feet 6 inches from rail to roof, and weighs about 40 tons. The full train has seating accommodation for 219 persons, and complete with full load represents a weight of about 280 tons.

The American train plies between Philadelphia and Atlantic City, which is to the Quaker City what Brighton is to London, only, whereas the English resort has an all-the-year-round season, that of Atlantic City is confined to the summer months, although now it is coming into favour likewise as a popular continuous residential and health centre. From Philadelphia to the sea is a distance of $56\frac{1}{2}$ miles, but inasmuch as the terminal station of the Philadelphia and Reading Railroad is on the west bank of the Delaware River, which at this point is about a mile wide, the first section of the journey is by steam ferry across the waterway to Camden, on the opposite bank, whence the train starts. The mileage is taken from Camden, from which station Atlantic City is $55\frac{1}{2}$ miles distant, but the timing is from Philadelphia terminus. Ten minutes are allowed for embarking on the ferry, crossing the river, and transferring to the train, which therefore is scheduled to cover the $55\frac{1}{2}$ miles in 50 minutes—an average speed of 66·6 miles per hour.

In order to obtain a closer parallel between the English and American trains it would be necessary to imagine the Thames a mile wide, stretching from Victoria Station to the south end of Grosvenor Bridge,

and negotiated by ferry. But although the latter is eliminated from the English conditions, there is a stiff bank on a sharp curve outside Victoria Station, rising at 1 in 50 for half a mile, which is against the train starting from rest.

The composition of the American train is closely analogous to the "Southern Belle." As a rule it comprises six coaches of the Pullman pattern—a seventh is attached when the traffic is heavy—and the total weight hauled is about 280 tons loaded, exclusive of the engine.

The Atlantic City flyer was introduced in the summer season of 1896, and it aroused intense world-wide interest from its first appearance, owing to the high travelling speeds placed on record. On August 5th, 1898, it covered the $55\frac{1}{2}$ miles with six coaches and 285 passengers in $44\frac{3}{4}$ minutes, at an average speed of 74·4 miles per hour, the total load on this occasion, both engine and coaches, representing over 330 tons.

The speed was so high, and maintained so consistently day after day in each direction, that interest became centred in the engine. This was of a new class able to fulfil the speed conditions the company desired. It was of the 4–4–2 type, there being a leading four-wheeled bogie, four coupled driving wheels, and a trailing bogie under the fire-box. The drivers had a diameter of $84\frac{1}{4}$ inches; the driving wheel base was $7\frac{1}{4}$ feet; while the total wheel base was 26 feet 7 inches. Compound working was adopted, the high pressure cylinders having a diameter of 13 inches, and the low pressure cylinders a diameter of 22 inches, with a common stroke of 26 inches. The boiler was $58\frac{3}{4}$ inches in diameter, carrying 278 tubes, each 13 feet in length by $1\frac{3}{4}$ inches diameter, and having a heating surface of 1,656 square feet. The fire-box measured $113\frac{7}{8}$ inches in length by 96 inches wide, with a heating surface of 180 square feet, bringing the total heating surface to 1,836 square feet. The grate area was 86 square feet, and steam was maintained in the boiler at a pressure of 200 pounds per square inch. The total weight imposed upon the drivers was about 35 tons. The tender, mounted on two four-wheeled bogies, carried some 3,300 gallons of water. The driver's cab was placed in front of the fire-box, and mounted saddlewise on the top of the boiler.

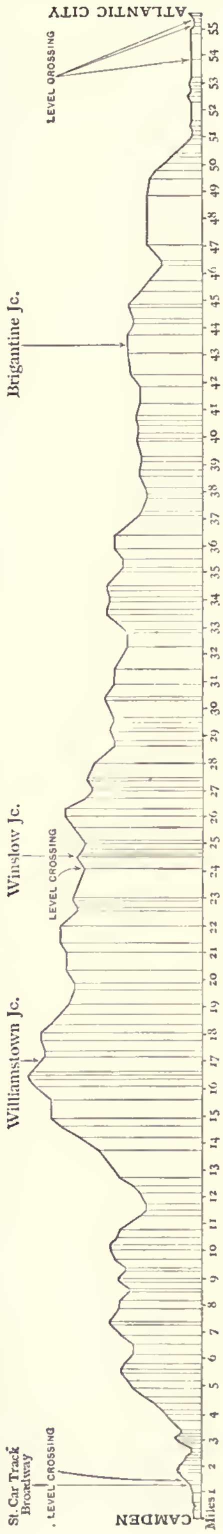
The story of the evolution of this engine is somewhat interesting. The Philadelphia and Reading Railroad built a 10-wheel engine comprising a four-wheeled leading bogie, and six coupled drivers. The company, however, desired an engine capable of sustaining its horse-power at high speeds, so the rear pair of driving wheels were changed to trailers, to obtain a deeper and longer fire-box than was possible with the six driving wheel arrangement. In this

THE DRAWING-ROOM CAR "CLEOPATRA" ON THE "SOUTHERN BELLE."

manner an increase in steaming power, so as to be able to haul heavy passenger trains at high speed, was secured. In this converted engine the trailing wheels were not provided with a truck, but were placed simply in pedestals and set in approximately the same place occupied by the removed pair of driving wheels. The experimental engine, proving highly successful in practice, became standardised for this service.

The performances of this class of engine becoming appreciated, it has been adopted practically throughout the world in a modified form, but is universally known as the "Atlantic," from its first appearance in connection with the Atlantic City flyer. Other countries have not followed the practice of placing the driver's cab over the driving wheels and forward of the fire-box, but have relegated it to the usual position at the rear of the engine. The Philadelphia and Reading Company, however, has retained the original design. The "Atlantic" engine which hauls this fast train to-day is identical with that which appeared in 1896, except that it is more powerful, in accordance with the progressive spirit of the age.

So far as the British and American roads are concerned the last-named has the advantage. The "Southern Belle" has one or two stiff stretches of heavy banks ranging from 1 in 56 up to 1 in 100, with curves of 660 feet radius. The most handicapping feature are the junctions, twelve of which have to be negotiated, and these necessitate reduction in speed.



CONDENSED PROFILE OF THE LINE BETWEEN PHILADELPHIA (CAMDEN) AND ATLANTIC CITY.

Although the Philadelphia and Reading Railway is less troubled in this latter respect it has its own peculiar adverse influences not experienced on the British railway—level crossings. The "Southern Belle" has to contend against congested suburban traffic working between Victoria and Croydon, whereas its American rival is affected only slightly in this connection, and is able to get well into its stride before the first two miles out of Camden are covered. Whereas the "Southern Belle" is called upon to make spurts of speed on good sections of the road between busy junctions, and where 80 miles per hour often are notched, the Atlantic City flyer is able to maintain a steady gait throughout the greater part of its flight.

The "Southern Belle" makes the round trip between London and Brighton twice a day throughout the year. Its arrival five minutes ahead of time is by no means uncommon, while the occasions on which it has been half-a-minute late are very rare. Still, even under the most favourable conditions the speed achieved does not approach that of the Atlantic City flyer.

The fastest run placed on record by this express was made on July 20th, 1904, when the 55½ miles down were reeled off in 43 minutes dead, giving an average speed of 77·4 miles per hour. It may be pointed out that, although the fastest runs have been made on the outward journey, owing to the grade falling steadily and almost continually towards the sea-coast from the seventeenth mile-post out of Philadelphia,

yet the upward runs are equally brilliant. Nor have the highest speeds been attained

COMPOUND NO. 1027. ONE OF THE FIRST "ATLANTICS" WHICH HAULED THE AMERICAN FLYER.

The drivers were $84\frac{1}{4}$ inches in diameter, and the complete weight of locomotive and tender was $114\frac{1}{2}$ tons.

under conditions of light load, inasmuch as on August 20th, 1898, the train of seven Pullmans, carrying 505 passengers, left Philadelphia 45 seconds late, but arrived at Atlantic City $2\frac{1}{2}$ minutes ahead of schedule, the actual running time being $46\frac{3}{4}$ minutes with an average of 71·2 miles per hour.

Needless to say, this fine express is patronised heavily by season ticket holders, who, preferring to reside by the sea during the summer, yet demand quick communication between home and business. This train meets their convenience. On the up-journey it leaves Atlantic City at 8.15 a.m., arriving at Philadelphia an hour later; on the return journey it leaves Philadelphia terminal at 4.0 p.m. (Camden at 4.10 p.m.), reaching Atlantic City at 5 o'clock.

Although the "Southern Belle" still ranks as the crack train on the London, Brighton and South Coast Railway, this pride of place now is attributable rather to luxury and comfort than highest speed,

THE FASTEST 60-MINUTE TRAIN IN THE WORLD.

The Atlantic City flyer, which covers the $55\frac{1}{2}$ miles between Camden (Philadelphia) and Atlantic City in 50 minutes, hauled by type of "Atlantic" (4-4-2) locomotive.

seeing that one or two other trains cover the journey in the hour dead. But taken on the whole the running performances over the $50\frac{1}{2}$ miles between London and Brighton do not compare so favourably with the train service offered over the $55\frac{1}{2}$ miles between Atlantic City and Philadelphia (Camden Station). Of the twenty daily up trains, two cover the distance in 54 minutes, two in 55 minutes, three in 60 minutes, and six in 63 minutes. On the down journey, of the twenty trains one takes 53 minutes, two 55 minutes, two 60 minutes, and eight 65 minutes. But the hustling Philadelphian has become so accustomed to fast travelling over this system that he dubs the 65-minute expresses with two stops a "slow train!" A contrast to these flyers is the "parliamentary" train, stopping at all intermediate stations, which occupies two hours on its crawl from terminus to terminus.

Seeing that the "Atlantic" type of locomotive is utilised for the haulage of these two famous expresses a comparison of the engines used on the London, Brighton and South Coast and the Philadelphia and Reading Railways respectively is interesting.

	L.B. & S.C.R. No. 422.			P. & R. No. 342.	
Cylinders diameter .	21	in.	..	22	in.
„ stroke .	26	„	..	26	„
Driving wheels diameter . . .	$79\frac{1}{2}$	„	..	86	„
Boiler diameter .	66	„	..	66	„
Heating surface, tubes	1,346	sq. ft.	..	2,996	sq. ft.
„ „ fire-box	136	„	..	274	„
„ „ total	1,482	„	..	3,270	„
Superheater . .	460	„	..	—	
Grate area . .	30·9	„	..	94·5	„
Boiler pressure .	170	lb.	..	235	lb.
Weight on drivers .	38	tons	..	49	tons
Total weight of engine	75	„	..	$93\frac{1}{2}$	„
Tender . . .	39	„	..	$71\frac{1}{2}$	„
Complete weight of engine and tender.	114	„	..	165	„

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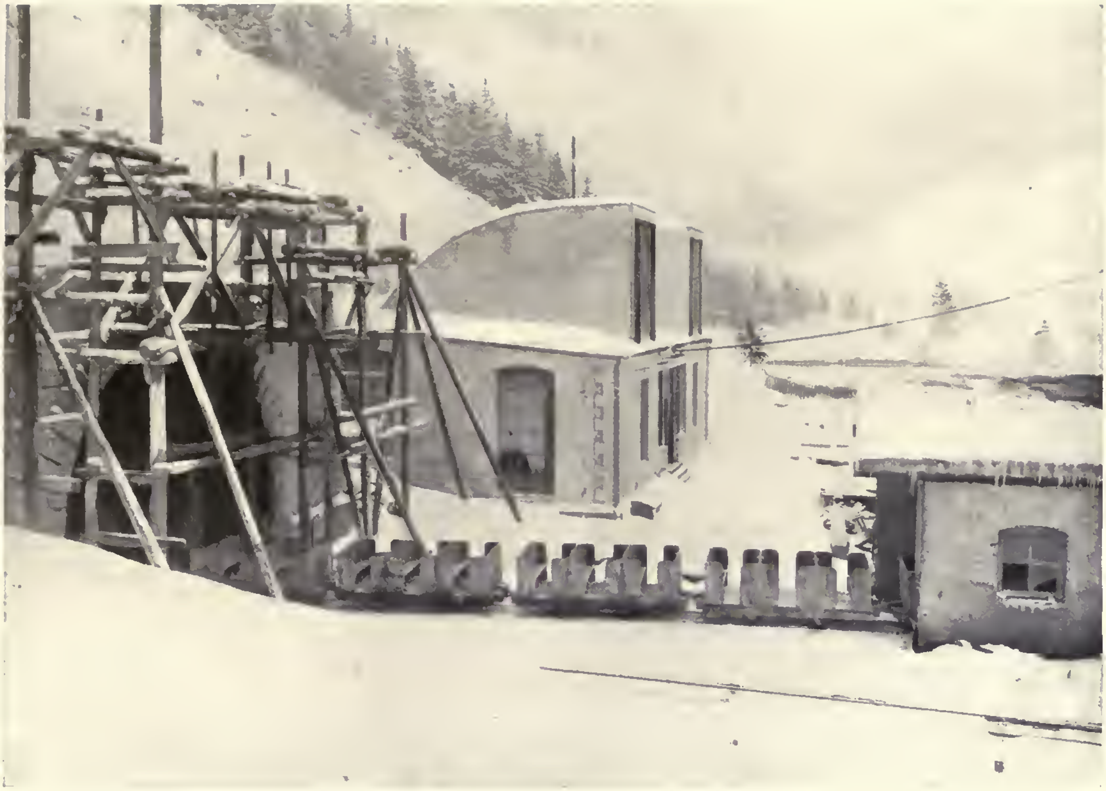


THE NORTHERN ENTRANCE TO THE LOTSCHBERG TUNNEL AT KANDERSTEG.
Showing workmen's train and ventilating pumping-station.

The Lotschberg Tunnel

NINE MILES IN LENGTH, THIS GREAT BORING THROUGH THE ALPS WAS COMPLETED IN RECORD TIME—4½ YEARS

WHEN the French and Italian nations announced their intention to burrow through the base of the Col de Fréjus in order to provide shorter and quicker railway communication between northern and southern Europe, the preternaturally sage shook their heads solemnly, said it was impossible, and that all kinds and descriptions of disasters, unknown to the engineer, lurked in the mountain's heart. But the railway builder was not distressed by the doleful outlook. He went ahead and confounded hostile criticism by completing the Mont Cenis tunnel.

One country viewed this achievement with dismay. This was Switzerland. Sandwiched between France and Italy, the obvious route between these two countries was through the tortuous passes and valleys of the land of the Alps. Yet here was the engineer deliberately turning the traffic to one side. Swiss pride and buoyant optimism were wounded. Their country was pushed into a siding, to be

THE TEMPORARY TIMBER VIADUCT AND CONSTRUCTION TRAIN.

forgotten, except by those anxious to gaze upon glacier and snow-crowned peak.

The prospect was somewhat depressing, but energetic Swiss minds shook up their countrymen and revived their spirits by pointing out that if French and Italian engineers could overcome the mountain chain so completely, surely the Swiss Alps could be pierced in a similar way.

The advocates of this forward movement painted their pictures so rosily that public opinion, like a pendulum, swung in the opposite direction. An Alpine tunnel fever broke out. Projects of all descriptions were rushed before the Government. Had every suggestion been adopted the Alps would have been honeycombed through and through, or the works have been left as gruesome monuments of the "Great Unpaid." While the public lost its head the authorities retained a cool, calm demeanour. The schemes were investigated closely; one after another was thrown out as hopelessly impracticable. From this maelstrom of ideas one project was singled out for distinction, and was finally carried into execution, though not before it passed through vicissitudes untold. This was the Gotthard Tunnel, 9½ miles in length, with its communicating approach lines.

Once a Swiss mountain had been subjugated successfully further schemes were adumbrated, and as they had been drawn up with greater care than those connected with the first tunnel frenzy, they demanded closer examination and more prolonged debate. Among these was one for piercing the Lotschberg between Kandersteg, in the Bernese Oberland, and Goppenstein, in Valais. It was an attractive proposition from whatever point it was considered, and although it had been mooted before the Gotthard enterprise was discussed, it was pigeonholed for further consideration at an opportune moment.

For forty years the proposers of the

Bernese Alps Railway clung to their dream. Although it was shattered first by the Gotthard, and afterwards by the Simplon tunnels, there was a general decision that the third line through the Alps should be under the Lotschberg, come what might. In this struggle Jacob Stampfli, who in due course became the first President of the Swiss Republic, played a very prominent part, and it was due to his grim pertinacity, with the support of his friends, that the scheme received official approbation in 1906.

The original project was torn to shreds under animated discussion, and numerous surveys were run in order to secure the most favourable route. The problem turned on the tunnel—its length and character. One section advocated strongly a "level tunnel" 13¾ miles in length, but this idea was thrown out by the Grand Council of Canton Berne. These discussions had been protracted partly from financial considerations. It was useless to sanction a scheme if the sinews of war were not forthcoming.

At this juncture the Paris banking house of Loste and Company stepped in, and offered to build a single track tunnel through the chain according to the accepted plans for 37,000,000 francs, as well as completing the approaches at each end, providing telegraphic and signalling systems and equipment for the whole of the line from Frutigen to Brigue for a further 37,000,000 francs. Thus the total cost of the undertaking was to be 74,000,000 francs, roughly £3,000,000. To this sum the Canton of Berne agreed to subscribe 21,000,000 francs, or nearly a million sterling. The total cost, however, became inflated subsequently to over £4,000,000, owing to the authorities deciding to have a double-track tunnel, and to unforeseen disasters which occurred during the work. Standard gauge, of

A BORING GANG WITH A MEYER DRILL IN THE HEADING.
The chief engineer of the tunnel is on the right of the group.

course, was adopted to permit through working with neighbouring systems, and at the same time the momentous decision was made to operate the line by electricity from its completion. The financial situation adjusted, the constructional company was founded, the contractors comprising Messrs. Allard, Chagnaud, Coiseau, Couvreux, Dollfus, Duparchy, Prudhomme and Wiriot. On October 1st, 1906, the agitation of forty years culminated in the signing of the contract for construction.

Hurried Preparations.

According to the terms of the compact the attack upon each side of the mountain chain was to be commenced by March 1st, 1907. Thus only five months were available for the elaborate preparations to be completed, and the country was among the wildest to be found in Switzerland! The railway ran as far as Frutigen, this section connecting with Spiez having been completed in 1901, while Brigue, on the Simplon line, was the southern terminus. From these two railway centres the contractors had to make their way to the tunnel faces over the winding and climbing mountain roads.

Temporary Towns Built.

The first step was the establishment of the necessary temporary towns to accommodate the workmen on the flanks of the mountain knot, the erection of depots, workshops, power-houses, etc. Convenient torrents near the respective portals were harnessed for the generation of electric current for a thousand and one purposes. On the north side these headquarters were founded at Kandersteg, while on the south side Goppenstein, in the Lotschen Valley, became a similar busy centre. A temporary narrow gauge railway had to be laid down from the trunk roads to the tunnel portals for the haulage of the material, both for the works and the workmen. This in itself was a heavy and difficult undertaking, involving the spanning of yawning ravines by timber viaducts, heavy side-hill excavation on sheer precipices, small tunnels, wooden bridges across wild torrents, the erection of massive timber supports to carry the track round blunt spurs, and the fashioning of loops in order to overcome abrupt differences in level.

Adventurous Work.

This work was full of adventure. Time after time the men had to be lowered on flimsy stages anchored by ropes fixed to iron pegs driven into the rock face, and there, swinging perilously in mid air, they were forced to drive their drills for the charges of explosives whereby a gallery was blasted out of the rock face. In fact, the men who built the construction line performed feats as startling, and experienced sensations quite as thrilling, as any encountered in driving the great bore through the peak, especially as the work was pressed forward with feverish energy.

While the completion of this light railway facilitated and expedited the hurrying of material to the unnel portals, it was not able to handle everything that was required. Some of the component parts of the machinery were too bulky to pass through the low tunnels, and they had to be dispatched to the site over the high roads. The ventilating blowers for the tunnel, for instance, had to be slung upon specially fashioned four-wheeled trucks, and hauled over the mountain path, with its sharp hairpin bends and stiff rises, by means of a dozen horses tended by as many men.

The Italian Navvy.

While the undertaking was Swiss in character, only the engineers were of this nationality. The workmen were drawn from sunny Italy, and when the task was in full swing as many as 4,000 Italians found employment. The Italians are adept rock-hogs, as such tunnel works as the Cenis, Gotthard, and Simplon had proved only too well. Although their victualling requirements are small and somewhat monotonous in character, they appear to be suited to the gruelling task

TRAIN-LOAD OF SPOIL FROM TUNNEL REPRESENTING ABOUT 3 FEET ADVANCE THROUGH THE ROCK.

of working ponderous drills in a cramped, depressing atmosphere, while they are highly skilled in blasting, and hard workers. This is one reason why the Italian railway navvy is in keen demand the whole world over, and why he is to be found toiling in the rock and earth, wherever the climate is not too wet or too cold.

The completion of the preliminary preparations occupied 28 days, so that the contractors commenced their attack on the mountain faces four months in advance of the contracted time. As events proved, these four months in hand were a boon, and gave them a bit of lee-way, seeing that they were working against a time limit. By the spring of 1907 there were two new humming towns in Switzerland—Kandersteg and Goppenstein—peopled by the Italians who had flocked thither with their wives and families.

Four Months Gained.

The plans called for the construction of 33 miles of railway between Frutigen and Brigue, of which the tunnel itself represented $8\frac{1}{2}$ miles. The great bore was to be perfectly straight, rising from 3,935 feet above the sea at the Kandersteg entrance with a grade of 1 in 443 to a summit level of 4,594 feet, which is reached about $3\frac{3}{4}$ miles from the northern portal, and then falling 1 in 263 to Goppenstein. Subsequently a revision of the location had to be made owing to the development of the unexpected. The tunnel is of the ordinary arched section with a maximum width of 26 feet 3 inches, a height of 19 feet 8 inches from rail level to the centre of the roof, and is lined throughout with masonry 18 inches in thickness. Water is carried off by a drain 2 feet square, laid in the centre of the tunnel.

Measurements and Gradients of the Tunnel.

The attack on the rock was commenced with hand labour, but directly the main body of the mountain was reached manual effort gave way to mechanical drills driven by compressed air. The tunnel borers were able to profit from the experience gained in connection with the previous Alpine tunnels in regard to tools and methods. Several types of drills were employed in the headings, but the Meyer and the Ingersoll gave the best results. The drills, of the rotary type, were mounted on a wheeled carriage, having a wheel base of 6 feet, and in such a manner as to have both a vertical and horizontal swing. They were of large size, the piston having a diameter of $3\frac{5}{8}$ inches.

As usual, the tunnel was driven from two headings. The lower, along the floor level, in advance of the top heading, which was excavated to the roof. The spoil as brought down by the blasts was dumped from the upper level through uptakes into the ballast trucks below. This line was of narrow gauge, and served for all transport purposes, being hauled in the tunnel by compressed air locomotives, and in the open air by small steam engines. As the forces driving the two headings advanced, other gangs followed, excavating the tunnel to its full section, commencing from the roof on either side of the top heading and working towards the floor. As the rock was removed the roof was timbered up to protect the men from falling rock dislodged by the firing of the blasts forward. Hard on the heels of the drillers and excavators came the gangs entrusted with the lining operation.

How the Tunnel was Driven.

Every big tunnel has brought its peculiar difficulties of a technical nature, tales of disaster, and loss of life. The Lotschberg was no exception to this rule. Most elaborate surveys had been made, and investigations carried out, to determine the geological formation of the mountain knot which was to be pierced. The experts stated that once the calcareous formation of the Fisistock was entered the bore would extend through hard solid rock. But here, as in other instances, scientific theories went agley sadly.

An Unforeseen Calamity.

The drillers were hard at work on the rock-face on the northern side, 600 feet below the floor of the Gastern Valley. It was 2.30 in the morning of July 24th. The drills had been withdrawn and wheeled back, the dynamite charges had been inserted and tamped home, while the men had withdrawn down the shaft beyond the reach of the concussion.

The dull, sullen roar reverberated down the tunnel, as it had done so often before, and the wave of wind created by the explosion swept down and extinguished the workers' acetylene lamps as usual. The men paused a second or two, and then in the ordinary way rushed towards the heading in the darkness. But the blast had brought down more than the estimated quantity of rock. It had let in the treacherous Gastern Valley, and a wall of glacial debris and mud came pouring down the heading. There were twenty-six Italians in the gang, and they rushed to their doom, for they were overwhelmed in the river of earth, gravel, boulders and water. Only one succeeded in effecting his escape. In less than ten minutes 250,800 cubic feet had poured into the tunnel, blocking it up for 1,731 yards, and not stopping in its rush until it had reached a point 1,209 yards from the Kandersteg portal.

HOW A BIG TUNNEL IS BUILT.
Showing the excavation of the Lotschberg to its full dimensions ready for lining and the timber shoring to support roof.

Work was brought to a standstill on the north side of the mountain. No one had considered it possible for the bed of the glacial valley overhead to extend to such a depth. As soon as possible an investigation was made, and huge fissures were discovered in the roof of the bore, where the loose spoil had burst into the tunnel. At the same time examinations were carried out in the valley, outside shafts being sunk into the bed of the ravine. Then it was

CHARGING A COMPRESSED-AIR ENGINE AT KANDERSTEG.

found that the glacial spoil stretched right down to within a few feet of the tunnel roof. Evidently this thin sheathing of solid rock had been shivered by the blast, and had let in the floor of the valley.

What was to be done? In this instance the unexpected had overwhelmed the enterprise with a vengeance. Various means of coping with the difficulty were suggested, but one and all were discarded as impracticable, either on technical grounds or from motives of cost. One solution was to drive forward with a shield and under compressed air build up a solid lining with the advance, as in the case of the tubes driven under the Thames. Another was to apply the freezing method, as has been carried out in sinking coal shafts through strata of treacherous sand, the ground for some distance around the site of the work being frozen solid while excavation is in progress. The contractors on their part suggested that a curve should be introduced to compass the treacherous area. The advocates of the straight tunnel, however, opposed this solution, and so work was held up while ways and means of overcoming the obstacle were discussed. This occupied valuable time. Meanwhile certain affected interests maintained that the contractors should clear out the tunnel and get over the difficulty as best they could and at their own risk, urging that as they had accepted the contract they must tolerate all such unforeseen circumstances. The contractors, however, sat tightly, and refused resolutely to do anything of the kind.

The months slipped by without any tangible solution of the problem being presented, and then the contractors were faced with another problem. A small army of men were condemned to idleness, and were eating their heads off at Kandersteg. The builders came to the conclusion that they must dismiss this colony, as

the delay appeared to be indefinite in its duration. This decision hurried matters, and the alternative advanced by the contractors for the introduction of a detour was accepted, the money to be paid for such deviation being left for decision by a court of arbitration.

The curve is introduced at a point 1,320 yards from the tunnel entrance. Thenceforward 2,940 yards of the old line, and the work accomplished, were abandoned. A heavy masonry wall was thrown up to seal the old heading where the curve commences. The introduction of the detour lengthened the tunnel by 880 yards, so that its total length was increased to 16,050 yards—over nine miles, and only 430 yards less than the Gotthard tunnel.

The men laboured unceasingly in shifts throughout the whole twenty-four hours, and for seven days a week. Each shift was of eight hours, and each gang was able to average two rounds of drilling and two shots per shift. In this way the tunnel advanced from 6 to 7 feet per shift, or about 18 to 21 feet per day. Every inducement was held out to the drillers to spare no effort. Above a certain advance per shift a liberal bonus was given, and many an expert Italian workman was able to earn eight or more shillings per shift as a reward for his toil.

The army advancing from the south side, although spared the peril of roof collapse and inundation, encountered their own troubles and difficulties. Water and hot rock harassed them within the shaft, and the avalanches created consternation outside. The stretch of hot rock proved very exhausting to the drillers, although the temperature, 90 degrees, did not approach that encountered in boring the Simplon.

A SECTION OF THE COMPLETED TUNNEL SHOWING LINING.
A compressed-air locomotive and train are seen on the tracks of the narrow gauge builders' railway.

The water was a more serious hindrance, as the subterranean springs, when tapped, poured into the tunnel with dismaying force and volume, so that the excavators often were compelled to labour in a murky stream, immersed to their knees, and at times almost up to their thighs. Still, inasmuch as water is a problem which has to be expected in such works, arrangements were prepared in anticipation, so that the hardship was reduced as much as possible immediately the danger developed, while the men on their part worked harder so as to get beyond the uncomfortable zone with all speed.

The Avalanche Peril.

The avalanche, however, was quite a different peril to combat. The Alps around the Goppenstein portal are impressively wild and awe-inspiring, the mountain slopes dropping precipitously into the Lotschen Valley. The snow, receiving a good start high above, gathered terrific impetus, and, rushing down the flank, hit the contractors' railway with fiendish fury, to bounce into the Lonza torrent below. Time after time the snow was found piled up to a height of 80 feet at the tunnel entrance.

But the worst calamity happened on the night of February 29th, 1908. In the canteen a party, including visitors to the works, were at supper. Suddenly there was a roar and a rush of air. An immense avalanche dropped in the heart of the little town. The hostelry was smashed, parts of it being hurled into the Lonza torrent, and of the thirty people dining a dozen were killed. The tunnel mouth was completely blocked by the snow and debris, while the post office, the gendarmes' station, and other buildings, belonging to the builders, were damaged severely.

Fighting the Avalanche.

The contractors immediately devised ways and means of combating this destructive visitor. High up on the mountain side, immediately above the tunnel entrances, massive masonry walls, termed "faldums," have been planted. These embankments are planted one behind the other, down the tracks frequented by the snowslides, so that the avalanche becomes broken up and rendered impotent. The faldums practically accomplish the same end as the split fences planted above the Canadian Pacific upon the flanks of the Selkirks, only, in addition to deflecting the movement of the snow, they break it up, so that the avalanche is thrown in all directions, but clear of the railway tunnel entrance. The stretch of line immediately outside the Goppenstein tunnel mouth is exposed fully to the avalanche, and here the contractors planned an ingenious defence. Parallel with the railway on the mountain-side, a massive wall 30 feet in height, and some 8 feet in thickness at the base, has been built. Behind this wall the mountain side has been scooped out, so as to form a curved trench. The avalanche sweeping down the mountain-side dives into this hollow, and, under the impetus it has attained, flies up the opposite curved wall into the air to describe a big sweep clear of the line into the gorge below.

How the Work was Done.

The scene in the tunnel was thrilling in its weirdness. A gang of miners stripped to the waist, and wading knee-deep in the murky water, their bodies gleaming brightly from perspiration and water dripping from the roof, worked like slaves, handling the huge drills and throwing the spoil into the trucks of the ballast train shunted up close by. Hanging from friendly projections or placed on convenient ledges were the acetylene hand lamps belonging to the workmen, each man being expected to purchase his illuminating device and to keep it in repair. The white light from these lamps mingling with the dust and smoke-laden atmosphere gave the scene a ghostly touch which was thrown into stronger relief by the Cimmerian darkness in the bore behind. Scarcely a word was spoken, the intense silence being

broken only by the ceaseless chugging of the drills.

Presently the drills had eaten their way to their utmost limit into the rock face. The carriage was drawn back, cartridges inserted into the perforations, tamped home, and fuses connected up. Then the drill carriage was backed down its track a few feet, while immediately over the rails was laid a heavy steel plate some 8 feet in length by 4 feet wide. There was a sharp order. Every man, picking up his acetylene lamp, retreated to a point down the bore. There was a final warning to make sure that every man was out of harm's way, and then the fuses were lighted.

The Critical Moment.

Intense silence reigned for a few seconds. Then came a smothered, long-drawn-out roar as cartridge after cartridge was fired, a splitting and a rending as the rock was torn in all directions by the expanding force of the gases of the explosive. As the roar travelled down the bore it was followed by a hurricane gust of wind, which extinguished the lamps. The sudden transition from glimmering light to inky darkness was unnerving. Ere the detonations had died away there came a fiendish clatter, as if the roof of the tunnel were coming in. The atmosphere was charged with suffocating fumes of the fired explosive, and the dust torn out by the explosion. Breathing was difficult, and the men coughed, spluttered, sneezed, and panted in the effort to clear their lungs, until, the ventilating fans getting the upper hand, the air was cleared. One after another shafts of light shot out through the fog, as the men relighted their lamps, and then there was a rush to the rock face, the men swarming over a dishevelled heap of jagged and splintered boulders. The leading toilers set to work feverishly clearing away the debris piled up on the heavy steel plate, which was removed, and the drill carriage pushed forward so that the cutting edges found purchase upon a fresh face of rock. The clearing gang tossed the shattered muck into the waiting ballast wagons, and in a short while the area in front of the drill carriage was quite clear. The loaded train backed down the tunnel into the open air with a load representing some 3 feet advance through the mountain heart, to dump it farther down the line, either for an embankment, or to spill over the torrent bank near the tunnel mouth.

The Piercing of the Mountain.

Early in 1911, when the men working on the Kandersteg headings had paused to fire the shots they heard a very faint throb, throb, throb—the explosions of the shots on the south side. The engineers computed that the miners were working on the last thousand feet of rock. Every day the sounds of the opposing blasts grew louder and louder. The end came on March 31st, 1911. At midnight, scarcely 4 feet of wall remained between the two parties.

The actual breach was detected by a miner on the Goppenstein side, who sent his drill into a hole only to notice that it failed to bite; it was through. Excitedly he withdrew the drill and broke out into frenzied cheering. His comrades, realising the import of his *vivas*, became infected with his enthusiasm, and huzzas rang down the bore towards Goppenstein, to be taken up a few seconds later by those on the Kandersteg side.

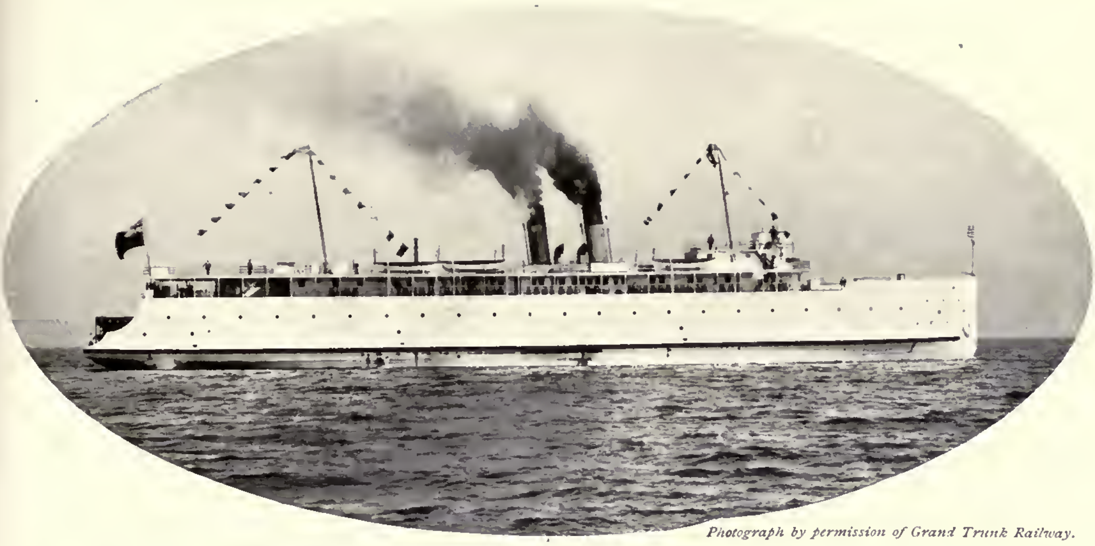
The remaining drill holes were driven quickly and excitedly, the last charges were tamped home, and the men on each side of the remaining veil of rock backed away. With a cheer the blast was fired at 3.50 a.m., and ere the detonation and crash of falling stone had died down, M. Moro, the chief engineer on the south side, because his party had discovered the final penetration and had brought down the last thickness of rock, crawled through the hole to greet his colleague on the other side. The toil of 4½ years was completed; the Lotschberg was penetrated.

Driving a tunnel 9 miles in length in 4½ years set up an achievement of which the Swiss are justly proud. It was additionally remarkable because of the delay of 200 days which arose from the irruption of the Gastern Valley, and the necessity to make a sweep to avoid this treacherous spot.

While the great tunnel constitutes the outstanding feature of the railway link between Frutigen and Brigue, the remaining sections of the line possess many striking examples of engineering. On the northern side there is the Mittholz loop, where the railway describes two big spiral turns, owing to the railway having to overcome an altitude of 1,385 feet in 7·8 miles. One loop is in the open while the other is in a corkscrew tunnel 1,830 yards long. There is also some daring bridge and viaduct work along the line, while between Goppenstein and Brigue no fewer than thirty-seven small tunnels had to be bored.

The Lotschberg tunnel offers a short cut between London and Italian ports. Formerly the detour by way of Lausanne and the Rhone Valley was necessary to reach Brigue and the Simplon tunnel. The new direct route runs by way of Spiez and Thun, where the Bernese Alps Railway commences, the distance therefrom to Brigue being 48·48 miles. It will affect materially also the vast volume of commerce flowing between Northern France, Germany and Italy. The whole of the traffic over this connecting link is to be moved electrically, for which purpose fine electric locomotives, some of the most powerful in the world, have been built. These are described in a subsequent chapter.

WALLS BUILT ON THE MOUNTAIN SLOPES TO PROTECT THE TUNNEL-ENTRANCES FROM AVALANCHES.



Photograph by permission of Grand Trunk Railway.

THE CAR FERRY *ONTARIO* AT FULL SPEED ON HER 56 MILES' JOURNEY ACROSS LAKE ONTARIO.

Floating Railways—I

THE ENORMOUS FERRIES IN WHICH TRAINS ARE TRANSPORTED ACROSS GREAT WATERWAYS IN CANADA AND THE UNITED STATES

THERE is one phase of railway working which is foreign to Great Britain. This is the train ferry. In these islands the interruptions of water, such as the estuaries of rivers, when they dispute the advance of the railway-builder, either are tunnelled or bridged. But there are some stretches of water which cannot be overcome in this manner. Thus, for instance, the Hudson River for many years proved an insurmountable barrier to through communication between the City of New York and the New Jersey shore. Only one railway ran direct into the heart of the city—the New York Central. Attempts to solve the difficulty were made many years ago by driving a " tube " beneath the river, but they were attended with disaster, and it was not until comparatively recently that the feat was achieved.

Meantime, the rapid growth of trade had prompted inventive ingenuity to discover another practicable way of surmounting the hindrance. The great lines which radiate to all parts of the country, in a natural desire to get into touch with the Empire City, have brought their lines to the water's edge on the New Jersey shore. At these points passengers change to a ferry, to be transported direct across the river. With merchandise, however, such a system was quite impracticable. The goods could not be unloaded on the New Jersey shore into barges, transferred to the opposite bank, and there handled once more : this practice would be slow and increase transport charges. Accordingly, it was decided to convey the trucks intact across the river.

These water-carriers are blunt-ended, dumb craft, euphemistically called "floats." Two sets of metals are laid on the deck with a narrow platform between, the float being of sufficient length to accommodate six large American box cars on each track. At the landing yard, the float is brought endwise against the land tracks, so that the metals are dead true with the rails running to the water's edge. If there is any difference in level it is met by a "bridge," or heavy flap, hinged at one end. The cars are pushed over this bridge on to the float, and made fast by scotching the wheels. When loaded, a signal is given, a powerful tug fusses up, lashes itself to one side of the float, and bears it across the waterway to the opposite yard, where the cars are pushed on to dry land once more over another bridge. The tugs are powerful vessels of their class, and if necessary can handle two laden floats at a time, thus transporting twenty-four loaded vehicles in one trip.

What the Ferries Accomplish.

From the British point of view, this seems a round-about method of handling the goods traffic, but in New York it has proved highly successful. So much so that 10,000 trucks are whisked to and fro every twenty-four hours. Over 2,000 floats are engaged in this service, and their handling gives employment to an army of 6,000 men. Although tunnels have been laid beneath the river, no appreciable diminution of this curious water traffic has resulted. It is easier and quicker to convey the cars in this manner than to send them through a constricted bottle-like passage.

The Hudson in Winter.

With this fleet of floats dodging to and fro the stretch of Hudson River washing Manhattan Island is a bustling scene of activity throughout the twenty-four hours. During the summer the traffic is controlled with tolerable ease, but winter tells a different story. When the Hudson River is choked with ice floes, buffeted to and fro by the tides, currents and winds, clinging round the ends of the piers, and littering the docks where the floats berth, the marine railways have a trying time. They make their way back and forth from sheer strength and weight. Nothing but steel could withstand the heavy poundings to which the floats are subjected. A dock may be half-filled with ice, but the float with its heavy load comes banging in, smashing its way through the obstruction, shivering it to small splinters which are sent flying in all directions, or else are piled up at the shore-end in a huge heap. Such a trifle as blocks of ice capable of bearing the weight of a man, and piled up by the elements, cannot be allowed to interfere with the scheduled running of the floats. When they have a good swing on them, these bluff-ended craft strike an obstacle with the force of a gigantic battering ram. There may be a temporary shock and shiver, the trucks on deck may grunt and clatter, but the float goes forward.

The Fog Fiend.

When the heavy winds which occasionally sweep up the Hudson estuary rage, the floats do not stop. The going is harder, that is all, but this handicap can be overcome by lashing two or even three of the powerful tugs to a load, to drive against Old Boreas. Even fog, which generally disorganises locomotion, has little effect upon this traffic. The vessels plough their way through the white blanket, whistling and shrieking for all they are worth, with the skipper of the tug keeping a sharp eye and ear on everything around him. When New York is gripped by the fog fiend, Bedlam is let loose. It is a discordant din: bells, sirens, whistles, fog-horns, and what-not are jumbled inharmoniously to produce an ear-splitting racket which would not be tolerated in any other country but the United States. The New Yorker tells you that his city is a business, not a resi-

dential centre, and so the noise does not count for much. Dollars can be made just as easily to an unmusical accompaniment. The din cannot be quelled, since the floats run on a time-table, similar to that of a train, and if more time than that allotted

THE DETROIT RIVER TRAIN FERRY *LANSDOWNE.*
This boat can carry a train of eight cars each measuring 72 feet long.

is consumed in the journey—well, somebody suffers, and the captain of the tug is resolved not to be the scapegoat if noise can help him.

Whose ingenious mind first conceived the idea of carrying trains intact across intervening wide stretches of water is not recorded. Certainly the idea originated in Britain, was transported, adopted, and developed in America, and since has reached its highest development in Europe and Asia. At all events an English shipbuilding firm, Wigham-Richardson and Company, on the Tyne, built a steam railway train ferry, the *Ruhr,* to carry railway vehicles across the Rhine before the bridge was built. That was way back in 1864. Seven years later, the idea having proved so successful, the Danish Government acquired a similar vessel, the *Lillebelt,* from the same builders, which is in service to this day. She is 140 feet long, by 26 feet wide, displaces 390 tons, is fitted with engines developing 85 nominal horse-power, and has a maximum speed of nine knots per hour.

The issue was forced upon the United States when the railway expansion westwards and southwards ensued. But unfortunately the strategical points, which were

certain to develop into great railway centres, are cut off on one side by wide sheets of water. San Francisco is situate at the extreme tip of the spit of land forming the western arm of the bay. Immediately opposite, on the mainland, is Oakland. The trains from the east came to a dead stop at this point—but Oakland is not the port. The railways could not make the long detour to compass the inlet, so ferries were adopted between the two points. It is a strange circumstance that the opposite ports on the Continent should be isolated from direct railway communication in this manner, and that San Francisco, like New York, should have only one line, approaching from the south, which traverses the spit of land, and thus enters the port over a dry-land highway.

The present San Francisco ferries are some of the finest of their class in operation. The west-bound trains crawl on to the ferry at the water's edge at Oakland. The craft, when its load is made fast, casts off, steams across the bay, and comes to rest against the ends of the track on the opposite bank. The train then creeps ashore and rumbles into San Francisco station. Some of the San Francisco ferries are of huge size, capable of accommodating fifty large freight cars and two or three engines in a single load.

THE TRAIN DECK OF THE *HURON*, WHICH PLIES ACROSS THE DETROIT RIVER BETWEEN WINDSOR AND DETROIT.

It can carry 16 freight cars each 36 feet long.

The same system has had to be adopted on the wider part of the Mississippi and Columbia Rivers. New Orleans is about one and a half miles away from Algiers. All traffic between the two points over the intercepting width of the Mississippi is

negotiated by the train ferry. On the Columbia River, just above Portland, a similar state of affairs exists, as the waterway is two miles in width.

The Great Lakes Ferries.

But it is around the Great Lakes that the most imposing illustrations of the possibilities of the floating railway are offered. These seas are transformed into one long waterway by connecting narrow straits, such as the Detroit and St. Clair Rivers. On opposite sides of the channel flourishing towns have sprung up. Thus there are Detroit and Port Huron on the American seaboard, faced by Windsor and Sarnia respectively on the Canadian shore. While the Canadian and American railways come down to the water's edge on either bank, the growth of international traffic and the flow of produce to and fro could not be interrupted or hindered by a neck of water half-a-mile in width. So where the permanent way was impossible the railway ferry was introduced, to float trains to and fro incessantly throughout the twenty-four hours the whole year round.

The St. Clair Tunnel.

This practice remained in vogue for several years, but the pressure of the traffic demanded more expeditious means of handling. This was particularly noticeable between Sarnia and Port Huron, as the interruption occurs on the busy main line of the Grand Trunk Railway between Montreal and Chicago. The urgency of improved connection was driven home by the increasing maritime traffic through the St. Clair River, and the fact that movement was impeded seriously by the ice during the winter. So the engineers searched for an easier situation. A bridge was impossible: tunnelling beneath the waterway was the only solution. This was accomplished, and with the opening of the St. Clair Tunnel, providing all-through railway communication between Montreal and Chicago, the ferry disappeared. The floating railway continues to run between Windsor and Detroit, however, although several years ago a similar situation to that developed farther north prompted tunnelling operations at this point. In this instance, however, at present the subaqueous continuous rail connection has not displaced the ferry traffic entirely. The Grand Trunk Railway, which also has a busy alternative international route, via Detroit and Windsor, maintains a fleet of three ferries upon the half-mile of water separating the two countries, over which the whole of the passenger and goods traffic flowing through this channel is moved. The largest of these steamers, the *Lansdowne*, is 319½ feet long, by 41½ feet wide, and 15 feet deep. The *Huron*, the second vessel, is 79½ feet shorter, but 2½ feet wider. Each craft can receive sixteen freight cars, each measuring 36 feet in length, or eight Pullman cars each 72 feet long. The third vessel, the *Great Western*, is still smaller, and has a proportionate lower carrying capacity.

The Lake Michigan Ferries.

The foregoing floating railways sink into insignificance, however, in comparison with those in operation upon Lake Michigan. This vast, elongated oval of fresh water is dotted on either side by busy ports, each of which is a teeming railway centre. Obviously, merchandise which has to be sent from one side of the lake to the other cannot be dispatched upon a long haul southwards to round the obstruction, neither is it profitable to load it into lake steamers. The cheapest and quickest method of coping with the traffic is to send it, packed in its trucks, across the water obstruction. There are many busy railway ferry lines, not only running across the extreme breadth of Lake Michigan, but also cutting across it diagonally, such as from Menominee to Frankfort, and from Manistique to Ludington. But the busiest marine railway thoroughfare lies direct across the breadth of the lake, between Milwaukee and Grand Haven, a distance

of 84 miles. In order to obtain a more realistic impression of what this means, the sea-journey between Newhaven and Dieppe, though eight miles shorter, offers a good parallel, as the conditions are very similar.

This is probably the busiest highway for this class of traffic in the world, and in its development Anglo-Canadian enterprise has played an important part, inasmuch as the finest vessels of this type are run by the essentially British Grand Trunk Railway. A progressive city like Milwaukee, with its 400,000 people and varied industries, found the lake a certain barrier to its progress, but when a means of shipping the products, after being packed in the railway cars in the factory yards, eastwards by the shortest route across the water was perfected, a new era dawned.

THE LOUNGE ON A CANADIAN CAR FERRY.

The ferries engaged in this service are the largest, most powerful and speedy craft to be found on the Continent.

The Grand Trunk ferries are named respectively *Milwaukee* and *Grand Haven.* The former is 350 feet long by 56 feet wide, and $19\frac{1}{2}$ feet deep, drawing $11\frac{1}{4}$ feet of water when loaded. Her engines develop 3,000 horse-power, and when fully laden with thirty cars each containing 60 tons—1,800 tons in all—she can notch a speed of 16 miles per hour. But merchandise is not the complete scope of her operations; she is available also for passenger service. Travellers, however, when condemned to a water journey of 84 miles, do not desire to be cooped within a railway compartment, lashed in a gloomy cavern between decks. Accordingly the ferry is provided with a passenger deck, and 30 state-

By permission of the Grand Trunk Railway.

THE *ONTARIO* BEING UNLOADED OF HER CARS OF COAL.

This all-steel boat is 316 feet in length and has a speed of 17 knots per hour. She plies across Lake Ontario between Cobourg (Ontario) and Rochester (New York), 56 miles. There are four tracks on her deck, and this small "yard" accommodates 30 coal cars, each carrying 50 tons =total carrying capacity 1,500 tons.

rooms for 90 first-class and 60 second-class passengers. The vessel also can meet another branch of railway traffic. In the dog-days of summer the industrial population of Milwaukee and other manufacturing centres indulge in merry-making, as in these islands. Mammoth excursions are planned, and in this traffic the *Milwaukee* assists very appreciably, as she is allowed to carry 3,000 holiday makers.

Cost £100,000.

Her consort, *Grand Haven,* while a trifle smaller, being 30 feet less in length and 18 inches narrower, reducing her carrying capacity by two freight cars, representing 120 tons, is faster. Her engines, developing 4,000 horse-power, give her a speed of 20 miles an hour. She, likewise, is adapted to the passenger-carrying trade, and has state room accommodation for 96 first-class and 154 second-class passengers. These vessels were costly, the *Milwaukee* representing an outlay of £100,000, while her sister cost £80,000.

The Ferries in Winter.

The modern Lake Michigan ferry is built of steel throughout, as nothing but this metal can stand up against the heavy battering and pounding of the ice. Although the lakes are frozen during the winter, driving navigation into hibernation for six months, the marine railway line must be kept open. Accordingly, the latest ferries are ice-breakers as well, so that they can smash their way through the thick glassy armour, the piles of floes, and the huge packs. It is an inspiring sight to watch these ferry boats attack an obstacle of ice. The 5,000 tons representing the weight of the vessel and its load charges the obstruction head on. The craft gives a momentary shudder as she hits the ice, but recovers herself immediately. The momentum she has attained is sufficient to thrust her forward, crunching, smashing, and throwing chunks of ice in all directions. As she drives her nose into a hummock, her bows are doused in a bath of spray and ice chips, for which a sharp look-out has to be maintained, as the flying debris cuts like glass.

If the obstacle is more than usually resistant, the speed of the vessel gradually slows down as she plunges through it, although her propellers are seeking to drive her forward. As the captain and engineer feel that the harnessed steam is being overpowered, the vessel is stopped and backed down the channel she has cut for herself, so as to have sufficient distance to get up speed once more to make another doughty "buck" at the ice.

A Ferry Disaster.

But running the railway ferries across the breadth of Lake Michigan is not all honey. This sea, in common with the others in the chain, is swept by the most violent storms, when the waves get up as high as any to be met on the Atlantic. Then the ferry has a hard gruelling, especially when the ice is about at the same time. Although staunchly built, engineering science in this field has not overcome completely the forces of Nature. Lake Michigan has its own tale of disaster, and has gathered its victims from the craft which seek to bridge the gap between the respective ends of the railway lines. The year 1909 was particularly black in this respect, and, the ice and storms being abnormally severe, even for Lake Michigan, sad havoc was wrought. The Pere Marquette steel car ferry *No.* 18 started out on her eastern trip with a full load of thirty laden coal-cars, and a crew of forty all told. Winter was jabbing its preliminary stings, and the sky looked sullen. But the railway ferry waits neither for weather nor season. The cars were lashed down with more than usual care, as there was every indication of a rough journey.

The Cars Break Loose.

The craft had barely got well out into the lake, and was ploughing along under full steam, when, with magic suddenness, the Arctic tempest burst over her. The 60-miles-an-hour gale catching the cumbersome,

loaded craft unawares, caused her to reel and stagger like a drunken man. The rough-and-tumble was so severe that before the crew grasped the situation two of the ungainly cars had snapped their lashings like pack-threads. All was confusion in an instant. The uncontrolled cars reared and plunged as the boat rolled and tossed. In the twinkling of an eye three men, run down by the breakaways, had been reduced to pulp. Even a steel-built vessel scarcely can withstand the pommellings of some 100 tons rolling about hither and thither, so intense alarm was felt by the discovery that leaks had been started, and that the stern compartments were being flooded.

The Cars Abandoned.

Instantly the pumps were got to work, and choughed like mad demons in the endeavour to keep the water down. One runaway, after wreaking widespread damage, responded to a heavy pitch of the labouring boat, and took a headlong dive over the stern into the lake. With much difficulty the second was got overboard. But although one danger had passed, another loomed up. The pumps, after working for three hours, became choked with ice, so that the water gained steadily.

There was only one chance to save the boat, and that was to lighten her. The captain gave the command to jettison the cars. It was a simple order, but one which was terrifying to carry into effect, when the ferry was writhing and twisting like an acrobat. Still, the crew, with that grit and determination born of desperation, sprang to the task. The cars were cautiously released when the boat steadied herself for a second or two, and then, in the twinkling of an eye, as the nose of the ferry rose to climb a roller, a car was let loose. The steep declination of the track enabled the cars to rush down with fearful force to smash into the water. Now and again, owing to the ship pitching nose downwards before the truck was clear, the rear wheels caught, and then the men had to toil like demons and with superhuman effort to prise the wheels over.

The Heroic Crew.

Meantime the ferry was settling down steadily. All but two of the cars were got off, when the captain gave the men the order to rush for their lives. They hesitated a moment, as the exertions of their task had diverted their attention from the plight of the vessel. But they obeyed the order. They had scarcely drawn clear, and were fighting grimly among the foaming waves, when, glancing backwards, they saw the ferry dip her stern as the bow met an advancing roller. But the stern did not rise as it should have done the succeeding instant. Instead, it was swamped, and never was seen again. The ferry sank like a floating tin which suddenly has its stability destroyed. The men pulled hard for the shore, no easy task in such a sea and with the thermometer well down below freezing point: of the forty who put out from port only two got ashore.

How the Trains are Embarked.

The method of bringing these floating railways into line with the land tracks at the water's edge is somewhat novel. The area for docking the vessel, which is just large enough to accommodate her and no more, is given a substantial fence of massive timber piles, the line of which follows the contour of the ship from the stern to amidships. The vessel backs into this enclosure very steadily, presently bumping gently against the fence. The piles give a trifle to the blow, but at the same time they guide the movement of stern until at last it strikes the end of the dock, when, the metals coming into line, bolts are dropped to hold the vessel firmly in position. In tidal waters connection between the railway and the ship's deck is maintained over a bridge, one end of which can be moved up or down to overcome the difference in level between the tracks on land and on board respectively.

On the other lakes, ferry services are maintained between important railway points on the opposite shores. Thus the Straits of Mackinac, where the waters of Lakes Michigan and Huron mingle, are spanned by these massive steel craft. These particular ferries, however, do not ply only between the facing railway terminals located on the respective banks, but at times embark upon coasting journeys, carrying their ponderous loads 60 or 70 miles down the shores. Lake Erie is spanned between Port Stanley on the Canadian side and Conneaut, Ohio, while Lake Ontario is bridged similarly between Cobourg, Ontario, and the Port of Rochester, in the State of New York, the sea journey being 56 miles. The ferry engaged on this service, *Ontario No. 1*, is a particularly fine example of the American-built marine railway. She has an over-all length of 316 feet, a beam of 54 feet, and depth of 20 feet, drawing 15 feet of water when loaded. Steel is used throughout in her construction, and the hull is subdivided by water-tight bulkheads, while her twin screws and engines are sufficiently powerful to secure a speed of 17 knots per hour. Her deck is a miniature railway siding with its four sets of metals, which are capable of receiving thirty American freight cars. While this ferry is fitted with a deck for passengers, and has an elaborate equipment, including a music room and a restaurant service *a la carte*, it is essentially a freight route. The Grand Trunk Railway Company and other industrial Canadian manufacturing interests draw their coal supplies from the Western Pennsylvania fields, which are served by the Buffalo, Rochester and Pittsburg Railway. The trucks, laden with 50 tons of coal, are brought up to Rochester and then transported directly across the lake for distribution to the desired points on the Canadian shore, the ferry handling a complete consignment of 1,500 tons of fuel in a single trip. In this instance the ferry saves a haul of 214 miles, since otherwise the fuel would have to be carried around the head of the lake, and enter Canada via the Niagara frontier—a detour of 270 miles. The passenger service, however is somewhat heavy, as many wealthy Americans have established summer homes on the Canadian shore of the lake, while the excursion traffic has grown very appreciably, this vessel being able to carry 1,000 merrymakers.

Photograph by permission of the Southern Pacific Railway.

HOW ENGINES AND TRAINS ARE TRANSPORTED INTACT.

THE STEAM SHOVEL, THE RAILWAY BUILDERS' MOST SERVICEABLE TOOL.

Few devices have facilitated and expedited railway construction so much as the steam navvy, which is capable of removing three or more tons of spoil at a time

Photograph by permission of the Bucyrus Company.

THE STEAM SHOVEL EMPTYING ITS CAPACIOUS MOUTHFUL INTO THE BALLAST WAGONS.

The Railway Builders' Heavy Artillery—I

THE STEAM SHOVEL, THE PLOUGH, THE GRADER, AND DRAG-LINE EXCAVATOR

IN the early days of railway building the tools employed for fashioning the permanent way were both primitive in character and limited in variety. The pick, shovel, and wheelbarrow were practically the only implements available and used. They were adequate for the time, but as the railway "caught on," and each country in turn fell a victim to the railway mania, the pace became so hot that the conventional methods of building the steel highway proved totally impracticable.

Ingenious minds at once set to work to devise mechanical appliances to expedite and facilitate excavating, transporting, and dumping the "spoil." Manual labour with white men is proverbially expensive, and under the most favourable conditions is relatively slow. Had the inventive faculty been lacking, and reliance placed upon the pick, shovel, and wheelbarrow, 50 per cent. of the railways now encircling the globe would have remained yet on paper. In such enterprises as the provision of railway transportation facilities the labour problem ever is acute, as much in new as in settled countries.

Among the wonderful devices which have been evolved to assist the railway-builder, the steam shovel stands pre-eminent. Ap-

THE RAILWAY BUILDER

The steam shovel making a "thorough" cut. It is digging its way down to a

Photograph by permission of the Bucyrus Company.

HANDIEST TOOL.

long the line of the railway, emptying its spoil into the ballast train alongside.

parently this useful implement is of British origin. Certainly in its primitive form it was a crude affair, comprising a vertical boiler, boom, pulleys, chain and small bucket, or shovel, mounted upon an ordinary railway truck—an improvisation purely and simply. Since those days, however, the implement has undergone a wonderful development, both in size and capacity, for the purpose of cheapening and expediting digging operations.

The Steam Shovel.

These tools follow the same broad principles of design the whole world over, though obviously they differ in details. Thus a description of one may be said to apply broadly to the whole class of this implement. The elements comprise the carrying truck, on which the steam operating engine is mounted, a boom or jib, the shovel proper, which in reality is a huge bucket, and the means for operating the latter.

In the largest and most powerful types the plant is mounted upon a long, two four-wheeled bogie car which carries the whole of the power-generating and operating plant, the machine thus being self-contained and able to do everything except propel itself. Complete, it may weigh anything from 40 to 100 tons in working order. The Bucyrus shovel, which has achieved a world-wide reputation, and which is in very extensive use in all the five continents, is typical of its class. It is a ponderous machine, and although made in a wide variety of styles, the type generally employed for railway building operations ranges between 70 and 80 tons with a bucket of 2½ cubic yards capacity.

These shovels run upon tracks of standard gauge, a short length being laid down for their accommodation in the cutting or ballast pit. When the earth has been removed to the limit of the shovel's reach from the front end of the track, the rails behind are taken up and relaid in front.

The shovel itself is swivelled upon the end of a long beam, known as the "dipper handle," which is carried at a point about half-way up the boom, and in such a way that it may slide by spur gearing between guides, so as to enable the dipper handle to be shortened or lengthened within limits to accommodate the bucket to the reach of the work. The upper end of the shovel is connected to chain or wire ropes, which, passing over pulleys at the end of the boom, and around sheaves mounted on the carrying trucks, enables the bucket to be lowered or hoisted. The empty shovel is swung out and lowered to the bottom of the bank, and then by means of chains or wire ropes is pulled up the slope to the top, the dipper handle keeping the shovel well pressed against the surface, so that by the time the shovel has completed the length of its upward travel it is filled with 2½ or more cubic yards of spoil, according to the capacity of the bucket. The upper edge of the bucket, on the side where it comes into contact with the soil, is fitted with massive teeth, which, as the shovel is scraped up the bank, dig and tear up the spoil, which falls into the mouth of the bucket. The load, with the teeth pointing upwards, is then swung round, until the huge mouthful of earth is over the ballast wagon, when the hinged bottom of the bucket is opened, and the contents fall into the waiting truck.

In some instances it is only the main boom which can be swung round within certain limits to enable the spoil to be dumped, but in other cases the entire mechanism is mounted upon a turntable, so as to enable the whole to be rotated, a circular track, carrying small rollers, being laid upon the deck of the truck for this purpose.

The "Thorough" Cut.

When a new railway is to be built the steam shovel commences operations right away, unless a cutting is to be made on the side of a hill. A temporary track is laid to one side of the location line to carry the train of ballast wagons. The steam shovel track is laid upon the location,

and the implement drives what is known in railway builders' parlance as a "thorough" cut. It digs its way down to the plotted level, swinging round its bucket with every mouthful to dump the removed earth into the trucks alongside.

When the shovel has completed this "thorough" cut it is backed out of the trench. The ballast wagons are now run upon a track laid through this cutting, the shovel making drives through the bank first on one and then on the other side of the "thorough" cut, until the excavation has been opened out to the designed width. If a very deep cut has to be made through the hump in order to get down to the plotted level for the line, the shovel will make two or more trenches through the hump at different levels, until the requisite depth has been reached.

The introduction of the heavy powerful steam shovel has not failed to influence the design and capacity of the wagons employed for the removal of the excavated material. The tiny narrow-gauge wagon of about 4 cubic yards' capacity is not efficient or economical when working in conjunction with a big steam navvy, so larger and more capacious trucks have been evolved for working on a temporary standard gauge track. These cars are provided with sides, but no ends. Boards are laid across the gaps, both on floor and sides, between succeeding trucks, so that the train resembles one long continuous wooden trench on wheels. Thus a laden ballast train may easily represent a continuous ridge of earth 100 to 150 yards in length. These cars are emptied in a special manner, as described later. Or the vehicles may be of the automatic dump type, capable of carrying 16 cubic yards of earth, which is discharged through bottom-opening doors, to secure even distribution of the spoil when building up an embankment from a timber trestle.

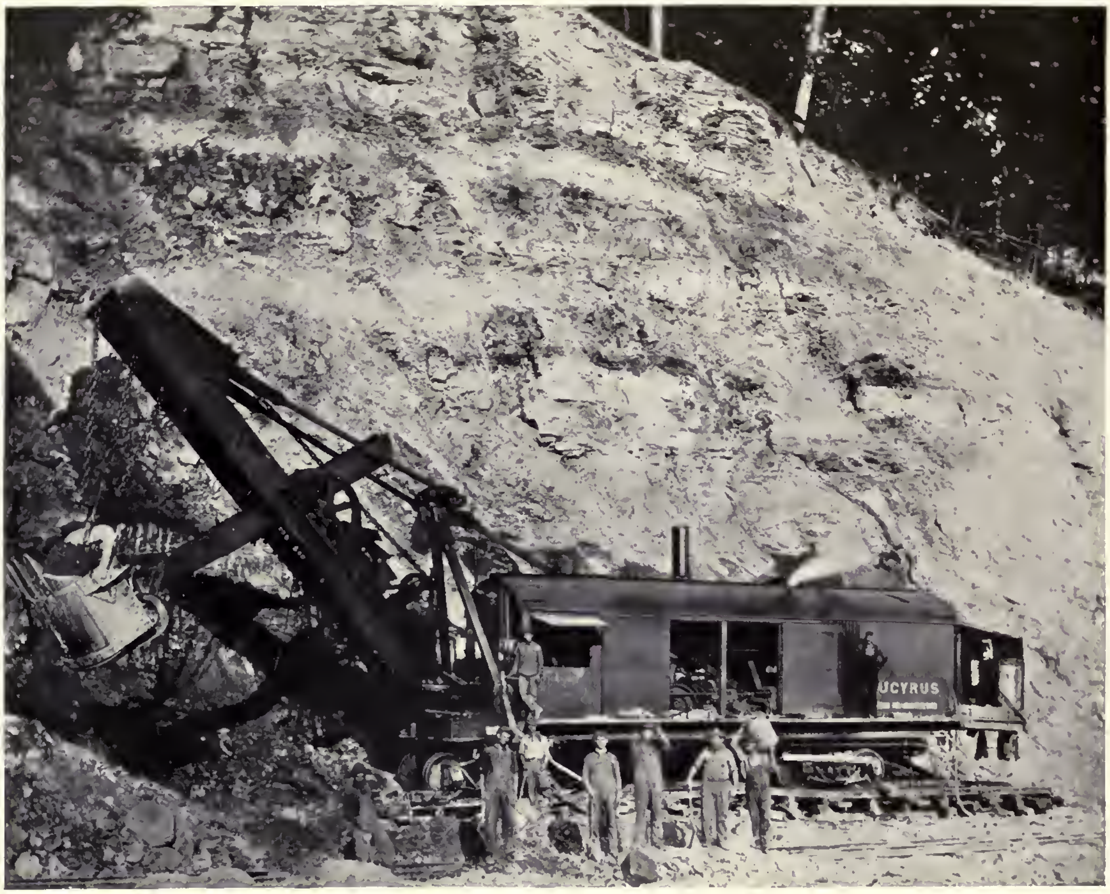
When the steam-shovel first was introduced its application was limited to excavating such material as clays, gravel, sand, etc., classified generally as "common." As the power, strength, and capacity of the tool was increased it was turned to useful

THE MECHANICAL SHOVEL WORKING IN A TUNNEL AND DRIVEN BY COMPRESSED AIR.

account in connection with the removal of earth associated with stones of small size, which is generally rated as "loose rock." But when railway construction was carried into the mountains, where the builders were faced with dense hard rock which had to be brought down by explosives, it was found useless, since huge boulders one and two tons in weight had to be moved. Manual handling was slow and expensive.

Accordingly, a friend of mine, who had secured the contracts for building a transcontinental railway through difficult mountainous country, endeavoured to adapt one of his steam shovels to the task. But the experiment was a dismal failure; the tool

broke down under the strain of scooping up large ragged and heavy pieces of the rock. Convinced that it could be made to fulfil this class of work, he urged one of the steam shovel manufacturers to design him a more powerful tool. Some months were occupied in solving the peculiar difficulties which arose, but at last an experimental shovel was dispatched to the front and submitted to the test. The bucket was of small capacity, and although delays arose owing to breakdowns, the machine did its work effectively. It failed intermittently merely because it was insufficiently powerful and heavy. The railway builder, however, gave an order on the spot for half-a-dozen shovels for rockwork if the designers would undertake to give him a $3\frac{1}{2}$ cubic yards bucket. The order was fulfilled, and by the aid of those heavy weapons the track was carried through the mountains in far less time than the contractor ever had anticipated, although it was through dense hard rock the whole way.



THE STEAM SHOVEL PLOUGHING ITS WAY THROUGH A DEEP CUT.

The work these shovels will get through when the conditions are favourable is amazing. A $2\frac{1}{2}$ cubic yard dipper will shift 2,000 cubic yards of "common" in a single 10-hour working day, and in one case on record over 75,000 cubic yards were moved in a month, working 10-hour day shifts only, notwithstanding the fact that four working days were lost through minor delays. In fact, the working speed is governed very appreciably by the celerity with which the ballast trains can be marshalled alongside, so that the dipper can pursue its monotonous swinging without hindrance. Taken on the average a single shovel, requiring a crew of about

seven to nine men to attend to all requirements, will displace from 500 to 600 men toiling by hand, while often it will cope with work which could not be carried out by manual effort, under any circumstances, no matter how many men might be available for the purpose.

The saving that can be effected by the utilisation of the steam shovel is tremendous. While the cost of operation naturally varies according to local conditions—the cost of fuel and labour—on the average it will enable a contractor to undertake a job of large dimensions at from 9d. to 1s. per cubic yard. The fuel consumption ranges up to about 25 cwt., and from 800 to 1,000 gallons of water per 10-hour working day.

At the same time it is not always possible to bring the steam shovel into action, no matter how urgently it may be required. Seeing that a big railway undertaking will be attacked at twenty or thirty different points simultaneously over a distance of 100 or 150 miles beyond the railhead, and will possibly run through virgin country void of roads, the weight and dimensions of this implement militate against its dispatch to the advance grading camps, owing to the difficulties of transportation. A weight of between 70 and 80 tons is not lightly handled over rugged rough country.

As a rule, under such conditions, when the steam navvy cannot be brought up, other and lighter appliances are used for the time being. One of these is the plough, which is very handy for cutting off the tops of obstructing humps. It is similar in design to the agricultural implement, and is handled in the same way by horses. The top of the hump is cut up, and the displaced earth is pushed over the edge to roll down the slopes. While the system is slow, it is a serviceable makeshift until the more powerful mechanical tool can be brought up, and it is fairly efficient when working upon a confined area. The scraper is another tool which is requisitioned under

THE GRADER AT WORK.
This "tool" is worked by animal power, the horses or mules both pulling and pushing it along. The spoil is discharged into the wagon alongside.

Photograph by permission of the Canadian Northern Railway.

PLOUGHING OFF THE TOP OF A HILL TO LEVEL THE GRADE ON THE CANADIAN NORTHERN TRANSCONTINENTAL.

similar conditions. Drawn by a team of animals it scrapes up the surface of the ground, and the material thus removed is deflected and thrown to one side. The implement, however, can be used only where the soil is soft and easily workable.

The grader will do much of the work ordinarily performed by the steam shovel. This comprises a small plough, carried in a light small frame. From one side rises, at an angle of about 45 degrees, a short light lattice boom, around which travels a continuous belt of small buckets. As these latter round the lower point of the boom they are filled with the spoil cut up by the plough, and then travel along the upper side of the boom. In rounding the uppermost point of the ladder the buckets are capsized, and their contents shot into a capacious box wagon, which, drawn by horses, keeps pace with the grader. When the wagon is filled it draws to one side, to permit of another empty vehicle taking its place. The grader is worked by animal power, the horses or mules both pulling and pushing the tool. As many as 12 to 16 animals will be hitched to a single implement, and they continue the restless tramp up and down the cutting until the plotted level for the line has been gained. This is about the hardest task that can be imposed upon horseflesh in railway building operations, and only the strongest and most enduring animals can be employed, while even they fail to withstand the gruelling for very long without a change to lighter work. The mule appears to be better able to tolerate the exacting task than the horse, and consequently is used for preference.

During the past few years a new heavy tool, known as the " Drag-Line " excavator, has been brought extensively into service for railway building. It has proved exceptionally useful for raising embankments, working in ballast pits, and for making cuts through soft and water-logged ground.

The advantage is that it does not have to be placed in the cutting, but can be set on higher dry land on either side.

It is a somewhat lighter tool than the steam shovel, and the capacity of the buckets is somewhat less. It comprises a platform deck provided with a circular track and rollers to permit the whole machine to be swung round through a complete circle. The deck carries the whole of the power-generating plant, whether steam or motor, and hoisting-machinery, while from the front projects the jib, with pulleys, whereby the bucket is handled. The machine is bedded on a fixed foundation, instead of wheels, as in the case of the steam shovel, so that when its labours are completed at one place it has to be dismantled and re-erected at another point. The absence of portability, however, is compensated by the extreme working radius possessed by the machine.

The boom in the largest Bucyrus machines runs up to as much as 100 feet in length, and will carry a bucket of $3\frac{1}{2}$ yards capacity. The latter is suspended at its rear face from the end of the boom by wire cables passing over pulleys in the head of the jib. A second rope is attached to the front of the bucket, which likewise passes over similar pulleys, and thence to the sheaves. This is the digging rope, whereby the movement of the bucket is controlled by the operator, not only in filling and emptying operations, but also to slope the banks on either side of the cutting. A third rope passes from the nose of the bucket direct to the engine winding drum, wherewith the bucket is dragged along the ground and kept to its work.

In the manipulation of this machine a good deal depends upon the skill of the operator. The bucket is not merely run out and dropped from the end of the

Photograph by permission of the Bucyrus Company.

DRAG-LINE EXCAVATOR WORKING IN HEAVY CLAY IN A BALLAST PIT.

Showing how the ground is scooped out.

boom, but should be cast beyond the extremity of the latter. An expert operator with a 100 feet boom, under good conditions, can throw the bucket to a point 30 feet beyond the end of the jib, so that the working distance becomes increased to some 130 feet. As the bucket is dragged along the ground, the manipulation of its front cutting edge in conjunction with the movement of the drag rope enables it to scoop up the soil. When the bucket is hauled in, the machine is slewed round, and the contents either dumped into wagons for removal or discharged to build up an embankment.

The depth to which a machine with a 100 feet boom will excavate from one given point varies from 39 to 52 feet. The sharper the slope of the bank on which the machine is standing the greater the depth possible. If the operator is expert he can dig the slope, not only on the near, but also on the far side of the cutting, at $1\frac{1}{2}$ to 1, or less. Thus with the largest type of machine it is possible to make a cutting 25 feet deep and, with banks sloping at $1\frac{1}{2}$ to 1, about 30 feet wide at the bottom.

When first brought into service the machine was far from being satisfactory. It was practically an improvisation to meet peculiar situations, and good results were not obtained, except under favourable conditions. But the observance of the necessity to build this machine upon the same sound and substantial lines as governs the design of the heavy, powerful steam shovels has served to correct many of the objections concerning its utility.

The handling of spoil brought down by explosives in tunnels still is extensively carried out by hand, although the steam shovel is being utilised in this connection when excavating out to the full dimensions of the tunnel. So far it has yielded the most satisfactory results. In this application compressed air is employed as the motive power, steam obviously being impossible, as it would foul the workings.

Photograph by permission of the Bucyrus Company.

THE DRAG-LINE EXCAVATOR BUILDING UP AN EMBANKMENT.

HOW THE MUSKEG WORRIES THE ENGINEER.
A sink in the embankment of the Grand Trunk Pacific in Quebec.

Getting Out of Tight Corners

SOME EXTRAORDINARY INSTANCES OF THE RESOURCEFULNESS OF RAILWAY ENGINEERS IN DIFFERENT PARTS OF THE WORLD

WHILE the engineer is prepared to go anywhere, and is ready to achieve the seemingly impossible if the occasion rises, he always has his ambitions braked by one irresistible force—the hand which controls the purse-strings. As a rule the financier either does not or will not (owing to monetary stringency) see eye to eye with the engineer in the subjugation of an abnormal obstacle. This absence of sympathy was particularly noticeable in the early days of railway building, as then the item of cost was kept down with a very rigorous hand. The financier was ambitious, but wanted his dreams fulfilled for next to nothing, and was chagrined when the technical expert frankly told him that his ideas were impracticable—unless he spent money. When the engineer on his part came forward with ways and means of solving a difficulty, then the financier fired the eternal question, " What is it going to cost ? "

Yet in curbing the engineer the directing force often was responsible unwittingly for the performance of highly ingenious and daring pieces of work, which to-day arouse widespread attention. The engineer is a man of infinite resource, and when driven into a corner never has failed to rise to the occasion.

At the same time it must be pointed out that the engineer sometimes is baulked by a more formidable antagonist than lack

of funds. The physical characteristics may be dead against him. This was the case when George Stephenson, in building the Liverpool and Manchester Railway, decided to cut across, instead of running round the big bog, seven miles west of Manchester, known as Chat Moss. To dump ballast into this quagmire was akin to pouring water into a bottomless pit. Accordingly Stephenson introduced what is now universally known as the "corduroy" or mattress. Branches of trees, hurdles intertwined with hedge-cuttings, heather and what not were laid upon the surface of the bog and upon this the embankment was raised to carry the metals.

The Muskeg Trouble.

Probably the most powerful evidences of this method of overcoming similar stretches of soft ground are offered in America and Asia. The muskeg in the former and the tundra in the latter both coincide with our interpretation of a bog, being merely huge basins of great depth, in which the water has collected and has become associated with decaying vegetable matter, and trees which have rotted, the whole forming a mass similar to a soddened sponge.

In constructing the National Transcontinental Railway division of the Grand Trunk Pacific Railway, the muskeg has been a continual source of anxiety. The hinterland of Quebec and Ontario is a series of vast stretches of these morasses lying between the low-lying ridges of hills and mountains, beside which the 10 square miles of Chat Moss sink into insignificance. Every depression virtually is a muskeg stretching for miles, and the Grand Trunk Pacific, from its location, cuts across these wastes at right angles.

"Sink-holes."

The engineers indicated the trouble these swamps were likely to create when they made their surveys, and arrangements were completed in anticipation of a severe tussle for mastery. Time after time an embankment was raised and regarded as permanent only to collapse with dramatic suddenness. "Sink-holes" the navvies call them, and the name is appropriate, because the embankment simply sinks bodily into the morass, leaving the rails drooping in festoons through the air, or piling up an inextricable jumble of sleepers, metals, trucks, and broken trestling.

The Corduroy Remedy.

Elaborate corduroying was the only means of combating this exasperating difficulty. Fortunately, the bush on either side offered plenty of material in jack-pine, tamarack, hemlock, and other trees indigenous to such latitudes. They were cut down by the hundred, and woven into a thick mat. They were not trifling creations by any means. I have scrambled over some of them with the navvies, and they have been as thick as a man is tall, built up of trees measuring 4 to 6 inches at the butt, and laced firmly together to form a continuous pathway across the swamp.

As the ballast is dumped upon them they sink into the viscous slime steadily and surely, until at last no vestige of the mattress is to be seen. The builder continues to dump, little ballast trucks scurry to and from the ballast pits with thousands of tons of gravel and stone in an endless stream, until at last the sub-grade is brought to the required level. Then there is a pause, to see whether the fabric is taking a short rest before continuing its descent. It is as if the embankment were built on a huge hammock swung from edge to edge of the depression spanned in this manner.

Hardened by Time.

At first sight one might conclude that in time the support would collapse at several points, through the vegetable foundation rotting. But there is no such fear. The mattress sinks to a depth of several feet, and putrefaction cannot take place owing to the complete exclusion of air. As a matter of fact the corduroy becomes

stronger and stronger as time passes. The tree trunks become soddened with the water, and in the course of a few years are transformed virtually into petrified columns; or at any rate to the hardness and texture of bog-oak.

When the engineers carried the Trans-Siberian Railway across the wild wastes of Russia's Asiatic Empire, the same difficulties were encountered, and they could be subjugated only by recourse to the self-same expedient. Fortunately, these conditions prevail generally in densely forested districts, so that ample supplies of the raw material requisite for the mattresses are to be found upon the spot.

Sudden differences in level, with a lack of elbow-room, have been responsible for many notable achievements. When Meiggs set out to carry the steel highway from the Pacific seaboard of Peru over the Andes to the navigable waters of the Amazon, the mountains appeared to offer an insuperable obstacle. The peaks of this frowning chain differ from those found in other countries. They drop precipitously from dizzy heights amid the clouds into deep yawning chasms with walls as cleanly cut as if they had been dressed with chisels, and as vertically true as a plummet.

Meiggs followed the only available course. He pushed his metals forward by the aid of explosives as far as a friendly shelf of rock would permit. When this suddenly dropped into the gloomy depths of the ravine, he drove his line in the reverse direction up the mountain slope. The Stelvio highway, whereby the Alps are conquered, does not zigzag more bewilderingly than the Oroya Railway, which is virtually a series of sprawling "Z's" piled one above the other.

In order to rise from one level to the other the engineer introduced a solution which has since become widely known as the Meiggs "V-switch." It was a novelty in railway construction, but as he had resorted to all other known methods of getting out of a tight corner, he was forced to depend upon his fertile ingenuity in this instance. The V-switch, as its name implies, is a big "V" at the dead end where two sections of the railway ascending the mountain side meet. Instead of the train being hauled up one leg and pushed up the other, as in the zigzag or switchback, the train, upon reaching the apex, draws slowly forward until it is brought between the legs of another V set at right angles to the main track. This smaller V is laid upon a cleared hump. The engine is detached from the train, run forward a short distance, then backed down the leg of the V to its apex. The latter is a turntable, which, when the engine is

THE MEIGGS V-SWITCH ON THE OROYA RAILWAY.
This device enabled the engineer to conquer the zigzags upon his railway.

THE AMAZING TWISTS AND TURNS ON THE OROYA RAILWAY.
At the left is a dead end where the engine shunts to change ends of the train.

received thereon, is turned until the head of the locomotive points up the second leg of the V, along which it runs on to the main line once more. Now it backs on to the train, which is then hauled up the mountain-side until a similar operation becomes necessary to lift the train on to another level.

At other points direct shunting accomplishes the self-same end, as there is sufficient space for the purpose. At the dead end two tracks or sidings are laid down. The uncoupled engine runs forward, and by means of points is directed on to the second road, along which it backs a sufficient distance to be enabled to run on to the first road once more over a set of points, when it is reconnected to the train. It will be seen that in climbing the Andes the engine always hauls the train. Zigzagging in the usual manner would be dangerous, owing to the remarkable twists and turns described. The prevalence of landslides renders pushing up a slope dangerous, because the driver, in such a case, could not possibly see ahead of him, and might push the vehicles into a heavy pile of debris which had been brought down by the denuding forces of Nature and distributed over the track.

The Oroya Railway is an engineering wonder because the engineer was baffled at every trick and turn. The train while on its way plays a continuous game of hide-and-seek, as it darts in and out short tunnels driven through projecting spurs of the mountains. The sharp twists and turns are equally striking, the line doubling and redoubling upon itself in the most amazing manner.

If the engineer were called upon to build the Oroya Railway to-day, probably he

would resort to simpler means of gaining the various levels. It might mean the introduction of steep banks; but wherever the grade exceeded 1 in 22 recourse to a rack-rail would overcome the difficulty. This means of coping with abrupt changes in level has been adopted freely in subsequent railways among the Andes, such as the Argentine-Chilian Transcontinental and the Arica-La Paz undertakings, while all the steep stretches on the Leopoldina Railway are negotiated in this manner. For such services the engine is of special design, being a combined rack and adhesion locomotive, the cog-wheel coming into action when the rack sections are entered. The perfection of this combined engine has assisted the railway builder very appreciably, as zigzags, although effective, are far from economical in operation. They limit the capacity of the line very severely, while the length of track necessary to connect two particular points is about twice that required when the rack is used.

At the same time, however, by resort to such ingenious methods Meiggs was able to lift his ribbon of steel to a height of 15,665 feet above the Pacific in a distance of 107 miles. At places the presence of a gigantic peak demanded other solutions. He could not introduce a V-switch in the heart of the mountain. Then he mastered the difficulty by fashioning a huge loop, the greater part of which was carried through the dense rock, bringing one portal immediately above the other. In one instance

BUILDING THE ESPERANZA TUNNEL ON THE OROYA RAILWAY.
The railway entering the portal at right describes a big curve in the mountain to emerge at the higher level at left.

the two tunnel mouths are side by side, although one is about 30 feet above the other. The train enters one gloomy portal and follows a horseshoe bend in the heart of the peak, so that upon emerging the train doubles back upon itself, running roughly parallel with the path it followed to enter the pinnacle.

While Monsieur Favre was wrestling with the rock in the bowels of the St. Gotthard, his first lieutenant, Herr Hellwag, a clever German engineer, was pitted against some very teasing problems in the constricted, cramped valleys among the surrounding mountains, where heavy differences in level had to be overcome quickly. As the St. Gotthard Railway was to be a short cut across Switzerland between Italy and the north, it had to conform with trunk road requirements. Accordingly, switchbacks, zigzags, racks, and other simple means of meeting the situation were impracticable.


THREE DIFFERENT LEVELS ON THE OROYA RAILWAY.

With admirable ingenuity Hellwag introduced quite a new feature into railway engineering—the spiral tunnel; and some striking instances of his handiwork are to be found on both sides of the great Alpine tunnel. Going south, the railway, as it winds through the Reuss valley, climbs ever upwards to Goschenen, at the north portal. At kilometre-post $60\frac{1}{2}$ the line swings to the east side of the waterway and immediately plunges into the mountain side, where it describes almost an entire circle, approximately 1,050 feet in diameter. When it emerges from the mountain it is over the first portal, and then runs back for some distance. In the course of another half a kilometre the line plunges into a second peak, where it describes another big loop, forming the Wattinger tunnel, issuing from which it gains a still higher level. Thus, side by side, there are virtually three tracks on three levels, two running south and one

Photograph by permission of Swiss Federal Railways.

THE FAMOUS SPIRAL ON THE ST. GOTTHARD RAILWAY, SHOWING THE THREE TRACKS.

running north, while kilometre-posts 60, 63 and 66 are practically in line, the railway covering seven kilometres to advance one kilometre in distance.

In the Pfaffensbrung tunnel the railway describes a similar but slightly more elliptical spiral, while a double spiral is made south of Airolo, somewhat similar to that at Wassen, although there is no doubling and redoubling of tracks. Just after passing kilometre 99 the railway plunges through the Freggio tunnel, 5,143·6 feet in length, the circle being about 1,050 feet in diameter, the line passing immediately under the track by which the mountain was entered. Some $2\frac{1}{4}$ kilometres lower down the valley the railway once more darts into the mountain clump, describes another circle in the Prato tunnel 5,119·4 feet long, the lower being immediately under the upper portal.

But the most remarkable display of Hellwag's marvellous ingenuity is the manner in which he overcame the Biaschina gorge and its abrupt severe drops in level, for here there are two complete spiral tunnels side by side. The line enters the mountain flanks describing a complete circle of 4,972·5 feet. Issuing from this cavern, it runs down the valley for a short distance, and then describes another huge spiral in the Travi tunnel, 5,073 feet in length from end to end. Thus a rough figure eight is described on one side of the

THE WONDERFUL HORSESHOE CURVE

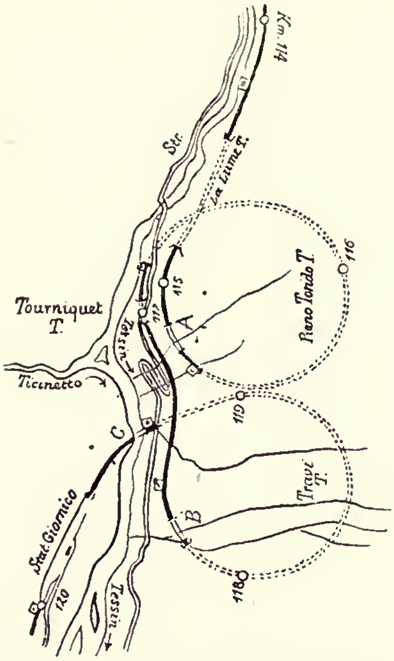
A sweep of $2\frac{3}{4}$ miles round the valley to preserve the grade. The

ravine, the two tunnel walls almost touching. This development work is marvellous, and as an engineering feat is worthy of ranking with the St. Gotthard tunnel itself. It is not surprising that, after this manifestation of ingenuity, Hellwag should have been elected to the position of engineer-in-chief of the whole enterprise when Louis Favre succumbed to an apoplectic seizure before the tunnel was completed. Hellwag's appointment, however, was received with unalloyed displeasure and jealousy; so after a short while he threw up the reins of the enterprise, virtually hounded from his post by piqued interests.

When Mr. Schwitzer was called upon to extricate the Canadian Pacific Railway from its tangle in the Kicking Horse Pass, and to eliminate the "Big Hill," so as to pull down the railway gradient, he did not hesitate to apply Hellwag's spiral solution to British Columbia, where similar conditions prevailed, as described in another chapter.

N THE PENNSYLVANIA RAILWAY.
stance in a straight line across the ends of the loop is one mile

The loop is another favourite method of overcoming sudden differences in level, and it is practicable so long as the engineer has space in which to describe the curves leading from one gallery to another. When David Moffat, the "Silver King," decided to take a new line as the crow flies from Denver to Salt Lake City, the frowning rampart of the snow-crowned Rockies stood in the way of his engineers. They received strict injunctions to surmount that tower-



THE DOUBLE SPIRAL TUNNELS ON THE ST. GOTTHARD RAILWAY.

ing obstacle by hook or by crook. The "Silver King" called for as straight and as short a line as skill and science could contrive. The city of Denver lies at an altitude of 5,198 feet above the sea, and to get over the range the engineers were compelled to carry the metals another 6,400 feet into the clouds, through a land of perpetual snow, and that within a very few miles, as the outer walls of the Rockies press hard upon Denver. A direct drive forward was impossible, so, after the engineers had got well into the range, they carried their ines ever upward in a bewildering, tortuous line, making huge loops and describing broad sweeping curves to the summit.

"The grade must be maintained." That is the governing dictum in connection with modern railway construction, and in pursuance of this policy some notable instances of development work are offered freely. Thus, on the Pennsylvania Railway the maximum mountain grade on the main line is 1·73 per cent., or an approximate rise of 92 feet per mile. At Kittaning Point the line emerges into a wide valley, and a point on the opposite side of the ravine, and one mile distant, is its objective. If a bee line were made across the gulch a grade of 4·8 per cent., or a rise of $253\frac{1}{2}$ feet in the distance would be required. Such a gradient would be prohibitive on a trunk line, as it would approach the maximum allowed generally upon a high road for vehicular traffic. So the engineer carried the line around the head of the valley in the form of a huge horseshoe. From end to end of the curve, and measuring along the central of the four tracks, the distance is 2·7 miles. Although, by making the detour, the mileage is nearly trebled between the two points as compared with a straight line through the air, the grade is pulled down from about 1 in 21 to 1 in 58.

On the South African railways travellers

ONE OF THE SPIRAL TUNNELS ON THE ST. GOTTHARD RAILWAY.

Showing the upper and lower tunnel mouths. The line makes a corkscrew ascent in the heart of the mountain to overcome the abrupt difference in level.

on the Maritzburg–Greytown line encounter the famous "balloon." This has nothing to do with aeronautics, as the name might imply, but is merely the colloquial description of the curious loop whereby the train is enabled to overcome the summit after climbing to an altitude of 860 feet in 7 miles. The name arose because the plan of the location on paper bears a striking resemblance to the pear-shape of the inflated gas-bag of a balloon. The loop has a radius of 300 feet, with a maximum gradient of 1 in 30, and at the neck of the balloon one track is 60 feet below the other.

For the most part, however, such interesting instances of development work are being eliminated from the great railways. Zigzags, switchbacks, spirals, loops are giving way, wherever practicable, to straight sections or easy curves, with the introduction of the rack railway and combined adhesion and cog-wheel locomotives to overcome abrupt changes in level. Tunnelling also is being adopted more freely as a solution, notwithstanding the heavier initial expense, in order to dispense with these evidences of engineering ingenuity, as the latter exercises a very appreciable augmenting influence upon the expense of running a railway.

TRAVELLING MILES TO CLIMB A FEW FEET.
The ascent of the Divide on the Moffat Road, showing the big loop

THE TONOPAH AND TIDEWATER RAILWAY IN DEATH VALLEY.
The engine hauls its water supplies. This photograph gives a striking idea of the sterile character of the country.

The Conquest of Death Valley

HOW THE RAILWAY WAS DRIVEN THROUGH THE ALKALI DESERT OF NEVADA

WHEN the steel ribbon was to be flung across Nevada's sizzling waste of alkali between Ludlow and Rhyolite, the name for the enterprise seemed obvious, if prosaic. But suddenly someone referred to the undertaking as the "Tonopah and Tidewater Railway." One of the engineers is credited with the expression, which must have been perpetrated in an outburst of cynical jest, seeing that the railway was to run neither to Tonopah nor to Tidewater. However, the two "T's" proved irresistible, and forthwith the undertaking was given the alliterative title. Since then it has redeemed its application somewhat, as the northern end now does connect with Tonopah, but the southern extremity is as far from the coast as ever; access thereto is provided over the tracks of the Atchison, Topeka and Santa Fé system, which runs through Ludlow on its western way to the Pacific seaboard.

Yet the engineer's inspiration was timely. Otherwise a lugubrious name, adapted to the surroundings, might have been evolved, because this important road traverses a dismal country where sinister sobriquets and grim traditions abound. It offers an easy approach to the ill-famed Death Valley, threads the lifeless Armagossa Canyon, skirts the Funeral Range, and carries the passenger to the purlieus of Skeleton Peak.

The few strange workers in this inhospitable corner of the world would have

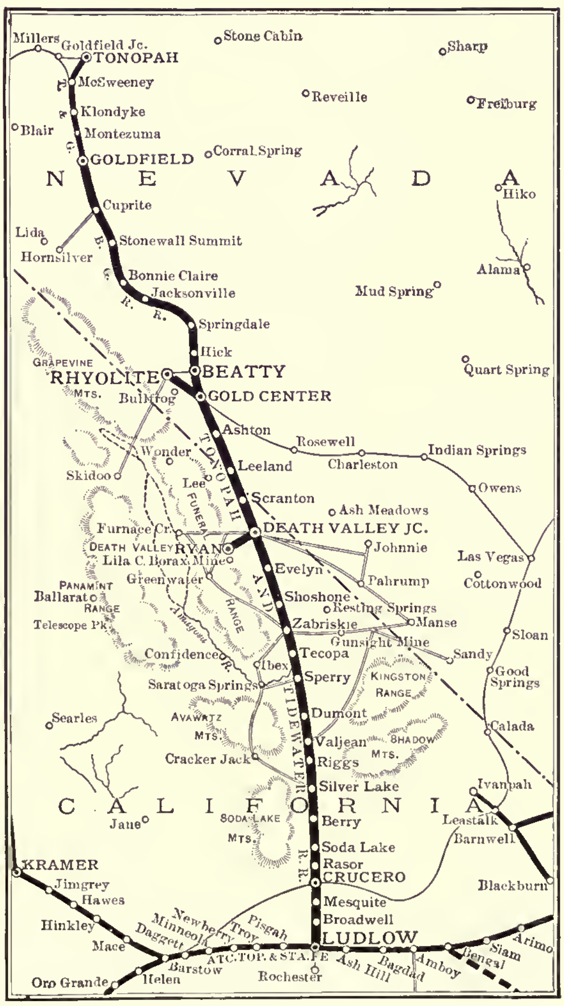
remedied the deficiency of title very promptly but for the engineer's ingenuity; they have a grim humour which is fitted peculiarly to circumstances. It does not demand a very vivid imagination to conjure such baptisms as the "Skeleton and Death Valley Fast Line" or the "Funeral Trunk Road." But, being forestalled by the engineer, and the alliterative title effectively combating all efforts to be superseded, the desert toilers have been forced to content themselves with nicknaming the trains, "The Skeleton Limited," "The Death Valley Express," "The Fast Funeral," and so forth.

Yet the "T. & T." railway itself is no joke. In fact, it ranks as one of the most important lines in the State. By linking up with the "Bullfrog-Goldfield" and Tonopah railways it offers a short cut across the length of Nevada. From end to end it traverses blistering desert, where the stunted cactus only can secure a root-hold, and where the coyotes and rattle-snakes are the predominant representatives of animal life.

Probably in no other corner of the North American continent is absolute sterility emphasised in such compelling form as the district served by the "T. & T." railway throughout its length of 175 miles. For years Death Valley was shunned as if stricken with the plague, and the surrounding desert was aptly described, with its eternal temperature ranging from 100° upwards, both day and night, as "Hades with the lid off." Its ill-sounding name is singularly apt, as it has been the graveyard of pioneers innumerable. Even the roving desert Indians, accustomed as they are to parched stretches of country and a precarious existence, give the "valley of skulls" a wide berth. Many intrepid spirits penetrated its silent, baking fastnesses, but few returned. The majority of those who limped back into civilisation were little else than living skeletons, with shattered nerves and unbalanced minds.

Notwithstanding this grim atmosphere, Death Valley ever has exercised an irresistible fascination to those who will not be baulked by any opposition of Nature in the eternal struggle for existence. The valley reeks with wealth incalculable. As a rule, it is the Golden Fleece which tempts the hardy and devil-may-care; but in this instance it was another magnet—borax. The world cannot roll along to-day without this commodity, and Death Valley is chock full of it. The floor of the depression—a lake in times gone by—is carpeted with soda and borax to a depth which never has been sounded.

The bold and daring were not prepared to let this opportunity to amass wealth



MAP OF THE DEATH VALLEY RAILWAY.

to pass without a determined effort to materialise some castle in the air. Small parties of gaunt, riotous, happy-go-lucky humans, who cannot occupy a niche within civilisation's bounds, started out to reach this grim, silent world. What cared they for the Red Man's advice to keep away: the Indian was an ignorant waster. The world demanded borax, and borax it should have, come what might. It was a straggling, terrible trek. Many collapsed on the way, and their bleaching bones gave a mute warning to those who came behind. Those who reached their goal waded in wealth and lived in caves. They became a race apart—ill-kempt, cadaverous, with beady eyes which glittered from fiery red sockets. They lived a prehistoric life, and were promptly described "desert rats" by those who were content to toil in more congenial surroundings.

"The Death Valley Express."

The success of these hardy, adventurous, and plucky prospectors tempted the capitalists. The "rats," although they had found riches beyond compute, were without all means of transporting their wealth to the markets. So they were financed to consummate this end. The desert demanded peculiar methods. These were forthcoming. Huge boxed vehicles, slung on large wheels without springs and with tyres 7 inches in width to prevent sinking in the soft sand, were built at a cost of £200 or so apiece, and were hauled by teams of mules, which, in their labouring over the blinding, thirst-torturing desert, became as gaunt as their human colleagues. Every train had hitched behind a capacious water wagon and a commissariat car wherewith the inner wants of both man and beast might be assuaged during the journey. It was a primitive train, and it rattled so slowly to and fro that the "rats" in their grim jocularity dubbed it "The Death Valley Express."

But things move quickly even in the desert when commercial development gets into its stride. One hardened prospector returned to the cities with specimens of low grade nitre, which he said abounded in plenty; another brought finds of copper; a third stumbled upon traces of silver; while immediately north of the country gold was found in rich paying veins.

The inevitable happened: the railway must be run into the country. That and nothing else could bring the region within the compass of commercial expansion and development. So the "T. & T." railway was born. A small band of surveyors set out from Las Vegas, the nearest station on the San Pedro and Salt Lake City Railroad, to drive their way westwards between the Charlston and Kingston mountain ranges into the sinister gulch. They brought back a feasible project, which was adopted without delay.

Conquering the Desert.

Construction was hurried forward. Large gangs of navvies, accustomed to driving the steel through the desert, were brought up with vast supplies of material and provisions. Las Vegas was to be their base, and they were to move forward like an invading army across the scorching wastes, with the completed track ever on the heels of all to bring up food and water, because the country traversed could not yield a drop of drinkable liquid nor an ounce of foodstuff.

Although a promising start was made with the grade, the enterprise was not proceeding smoothly. A dispute arose between the new concern and the railway with which it was linked, and the former was aggrieved. Quietly the "T. & T." approached the Atchison, Topeka, and Santa Fé system to see whether it could not be linked up with them. At the same time the surveyors were sent into the desert once more to plot a new route, in the event of the latest deliberations proving successful.

One evening in September, 1906, all the men working on the grade out from

Las Vegas reeeived a curt summons to "down tools." At the same time they were ordered to load all immediate requirements into a waiting train, and the desert had long been wrapped in the mantle of night ere the hurried task was completed. Then the navvies were ordered to take their seats, and without any fuss whatever the train steamed away to the south-west.

When the morning broke Las Vegas was deserted. Not a navvy was to be seen on the grade; there was not a single tool lying about. What was the matter? Had the new line met early sudden death? Yet what seemed to be an inscrutable mystery was soon solved by the ticking of the telegraph wires. The train which had departed so hurriedly overnight, ostensibly for the west, had stopped at the little station of Ludlow, on the Atehison, Topeka and Sante Fé line. The tools and supplies had been pitehed out, and the navvies were toiling for all they were worth upon a new grade. The San Pedro line had been thrown overboard: a rival had given what they had refused.

The engineers and their army of one thousand nondescript, hardened navvies set to work with great gusto: time had been lost on the initial unavailing start at Las Vegas. The standard gauge was adopted, since Tonopah was not the ultimate limit of northern railway travel.

Tradition, history, and superstition demanded elaborate precautions to preserve the humans slaving on the semi-roasting dust in laying the bond of steel.

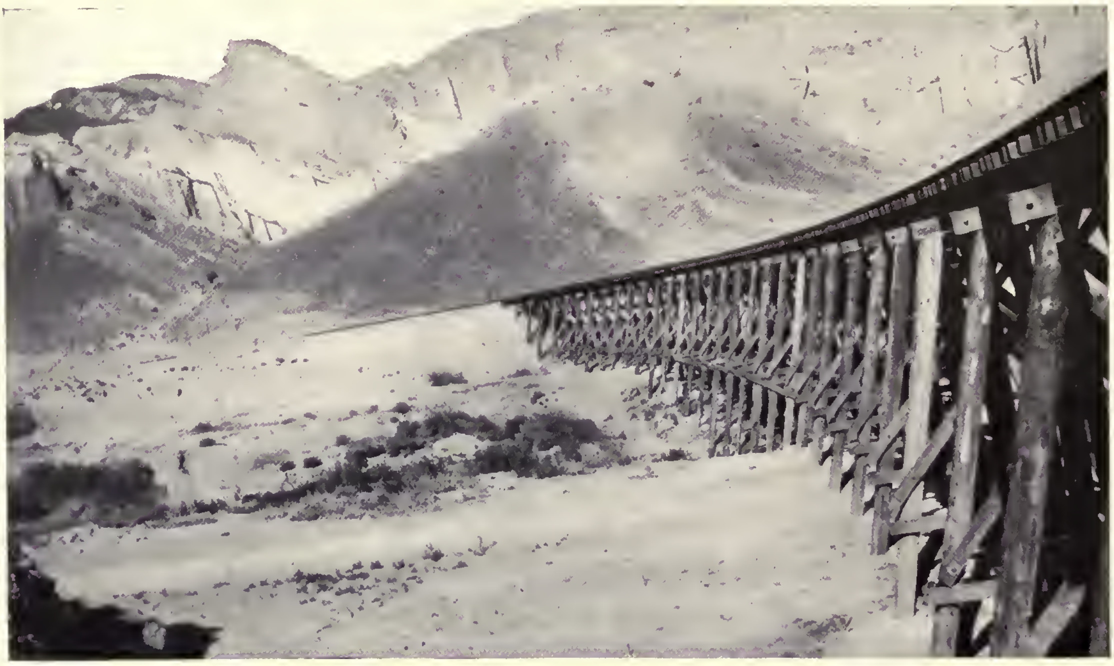
The railway grader is a eurious individual. He will labour hard and long uncomplainingly, tolerate unmereiful elimatie conditions without a murmur, and suffer isolation ungrudgingly so long as he is well fed. Moving a foree of a thousand men over a pitiless desert is anxious work under the best eonditions. While the navvies were busy wrestling with the heat and sand the controlling forces were ab-

THE TRACK THROUGH THE BLISTERING BORAX AND NITRE GULCHES.

sorbed in keeping the front well supplied with every little requirement. At night, when the graders had rolled themselves in their blankets and had laid down to a hard well-earned rest, the engineers in their little offiee at Ludlow worked far into the darkness, eompleting their teehnieal duties for the morrow under the flickering glimmer of oil lamps. Often the eastern sky had become well suffused with the eoming dawn before they turned in for

an hour or two's repose on the floor of their shack.

The construction camps were flung out over the drab desert for a distance of 20 miles beyond the point where the last rail was laid. Supplies were sent up by train as far as possible and then shifted onwards by mule teams. Beyond the rail-head straggled a pioneer telephone line, hurriedly built and of a most crazy-looking character, it is true, yet it kept the engineers in touch with the most distant camp. When an accident befell one of the men the engineers miles behind knew all about it within two or three seconds of its occurrence and were able to communicate temporary measures until the injured could receive the proper attention, which was sent forward without delay. Once a day the wheezy, borax-bleached construction engine crawled to the end of the steel highway with its tanks of water for the men, and rails, sleepers, comestibles, clothing, and letters. When it had shed its load it picked up those labourers who had received their fill of toiling in the silent desert, and brought them back.



A HEAVY STRETCH OF TRESTLING.
Every piece of timber had to be hauled several hundred miles.

The awful loneliness, torrid heat, dust-laden atmosphere, and silence were the great foes against which the navvies had to contend. When their day's work was done there were no welcome relaxations, except of their own creation, to wile away enforced leisure. Under such circumstances it is not surprising that gambling becomes the worst peccadillo of the hardened grader. They followed this amusement until its monotony palled, they were broken in pocket, or it failed to provide sufficient exhilaration.

Nevada has always enjoyed the reputation of being a quaint state where the laws are observed in a peculiar way, where the ideas of capital and labour have an unusual interpretation, and where Jack insists that he is better than his master. But on this undertaking there was never the slightest hitch or difficulty. The engineers took elaborate care that the inflammable prevaricator, alcohol, did not

invade the camps. Tea, coffee, and cocoa are not very powerful stimulants to quarrelling, and so the camps, with their rough-and-ready and riotously inclined inmates, were compelled to settle down in the manner of big families. Fortunately, it was not a difficult matter to secure prohibition. Illegal traders, who generally profit from such nefarious trade, did not appreciate the dangerous circuitous tramp over the desert: the risks were too great.

A Borax Swamp.

It was when the railway entered the Armagossa Canyon that the most difficult work was encountered. For part of the year this "sink" is a borax swamp; for the remainder it is an oven. The railway clings somewhat to the mountain side, and a gallery had to be blasted and hewn out, deep cuts driven through friable hills, and yawning depressions filled with the unstable spoil or spanned by lofty timber trestles. The slender line of communication was taxed heavily, inasmuch as every ounce of material had to be brought in; the country did not yield anything of value to the builders beyond earth for the grade. If a cord of wood were required for the camp fire, then the telephone clanged frantically, and the fuel was hurried up with as much speed as a consignment of spikes to clinch the rails to the sleepers.

The Navvy and the Desert.

It was a dreary northward pull. The mountain sides, catching the fierce heat of the sun, acted like firebricks and reflected a sultry glow when the sun had dipped behind the Sierras, so that night brought practically no relief. In the heart of this arid blotch upon the American landscape rises the Armagossa River, a stream of saturated soda and borax which, after running for a few miles, comes to a stop in a basin to dry up under the fierce heat of the summer sun or to be absorbed by the surrounding waste of borax, soda, nitre, and what not. As the graders pushed farther and farther into the dismal zone they became more and more sullen. The desert navvy is not a very loquacious individual at the best of times; but when his senses became dulled by the everlasting glow of glistening white he became taciturn almost to dumbness. To him there appeared to be only one object in life—to swing his tools mechanically for hour after hour with measured strokes, with intervals for refreshment. One wonders how men can be tempted to work under such conditions as these. The reason is not far to seek. Being toil of an unusual character, it receives enhanced pay. Desert enterprises have cultivated a peculiar type of navvy—a specialist in his craft, as it were. No greenhorns and tenderfeet were to be found on such work as this. A week or a month found them out; they were only too anxious to get as far away from Death Valley as they could.

The "Desert Rats."

As the graders drew near the haunted depression they secured a little relaxation: were confronted with fresh faces. The "desert rats" came out of their holes and burrows to watch the advance of the steel highway. As companions they were not a success. Locked up in the mountains, they had only tatters of news to discuss round the camp fires. They emerged rather for the purpose of hearing something from the graders. When all available items of news were worn threadbare the trend of conversation took a new turn, and some of the stories related round the camp fire when the day's work was done would make a town-dweller's blood run cold.

About 100 miles north of Ludlow a spur radiates from the main track into the heart of the Funeral Range, with road communication into Death Valley itself. Death Valley station is an important junction, and the "rats" will tell you that it is going to be "the ro'r'nes' place on earth." Three stations beyond is Gold Centre, whence the "T. & T." swings off west-

wards to Rhyolite. The traveller, determined to get to Tonopah, continues over the Bullfrog railroad to Goldfield, and thence to Tonopah on the northernmost rim of the desert. Thence the journey may be resumed by rail northwards through Carson City, finally gaining the Union Pacific Railway. Prior to the construction of the "T. & T." the great systems of the country described a big loop around the State of Nevada, as if fearing to venture too far into its arid wastes, so that to pass from Los Angeles to Carson City involved a long detour, either via San Francisco or by way of Salt Lake City. Now one is able to cut across the length of the State speedily and in comfort.

Triumph of the Railway.

When at last the railway was completed and the day of its official opening arrived, the event was celebrated in true Nevada fashion. All the great mining centres along the line let themselves go in the manner of the untamed West. The "rats" came down from the hills, and the miners came up from the depths with super-loads of cartridges. The train was greeted with a salvo from "automatics" and "bull-dogs," with a few detonations of giant powder and nitro-glycerine that had been left over from the construction work or brought in from the mines just to add foundation to the torrent of sound. Alcohol ran like water, or rather more furiously than the latter liquid, as the Nevada desert cultivates an insatiable thirst. There were speeches galore, and poets let themselves go with the vehemence born of spring. In fact, the stranger happening upon the scene might have been pardoned for thinking that he was the witness to the opening of a transcontinental, rather than a mere 200 miles of railway through a sun-baked desert. But the engineer had broken down the most grim and unsavoury corner of the continent, and that was worth all the jubilation expended.

Already the "T. & T." railway is making its presence felt. The communities scattered along the route, which formerly were designated mining camps, now scorn such an appellation. Every one is a "city"—or will be some day. The respective populations are increasing. The valley which has been silent and feared for so long is commencing to echo the droning of heavy machinery, which is being brought in to win the wealth from the dismal sink and shimmering brown mountains. Roads are being driven hither and thither to facilitate communication between the railway and the outermost parts of this wealthy country. "This railway means the opening of 20,000 square miles," one enthusiast remarked to me, and certainly such an expansion in a single stroke is a notable triumph for engineering science. Ludlow is coming into its own. From a handful of shacks standing beside a wayside station, which would never have been built but for a mine some seven miles away, it has grown into a hustling town and important railway divisional point, with engine sheds, miles of sidings, and repair shops. To-day the shacks spread far out over the flat, dusty country; there are streets, public institutions, and every other attribute that goes to constitute a prosperous, enthusiastic community.

Future of the "T. & T."

The future of the "T. & T." railway undoubtedly is governed by the development of the minerals abounding in the Death Valley country. But no apprehensions need be entertained on this score. Prospecting is being carried out upon an elaborate and scientific scale, possibly to reveal minerals which so far have not been identified with the country. Still, the output of soda, borax, nitre, silver, copper, and gold will suffice to return adequate dividends upon the money sunk in the effort to conquer this forbidding, scorched and ill-famed spot.

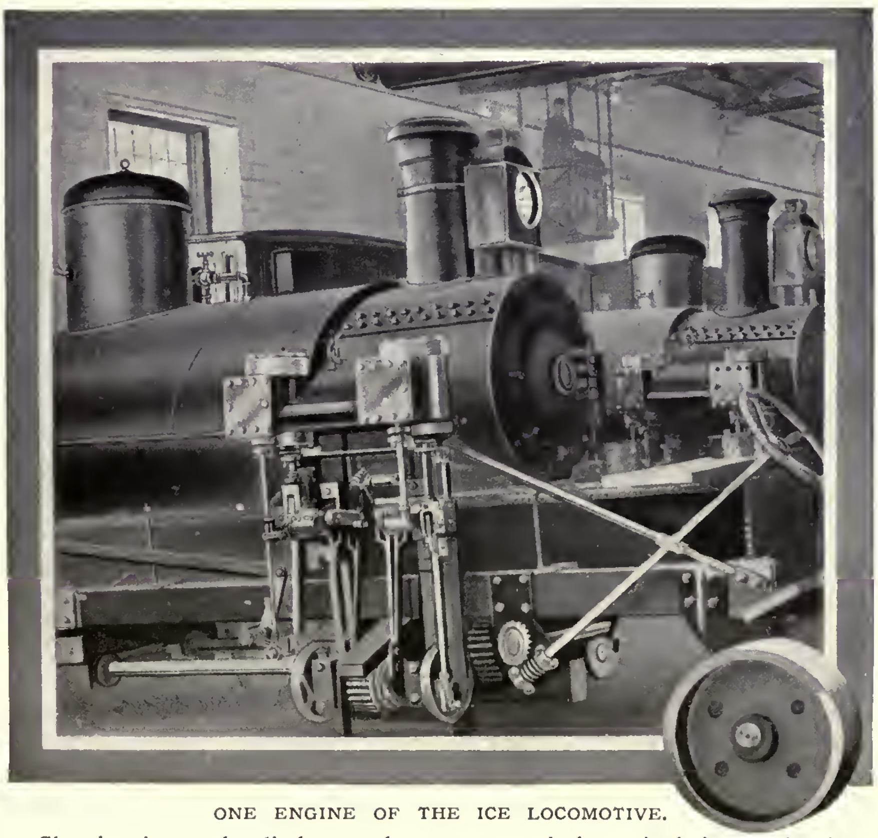
An "Ice Railway" Locomotive

A DEVICE THAT HAS REVOLUTIONISED THE LUMBER INDUSTRY OF NORTH AMERICA

ALTHOUGH the ordinary steel highway is harassed and often disorganised completely by the forces of winter, owing to the locomotive being unable to drive its way through the piled banks of snow, there is a certain type of "railway" which is inoperative unless the ground is snow-bound and frozen.

This is the "ice railway." Strictly speaking it is not a railway, since the vehicles do not run along a pair of metals. But at the same time it demands a defined track, the pathway being two parallel ruts. The locomotive is a hybrid, being a combination of the railway engine, traction engine and steam-driven automobile. The vehicles, instead of being carried on wheels, are mounted upon long runners which engage in and follow the ruts.

The "ice railway" has undergone considerable development during the past few years. It was created to meet the requirements of the lumbering industry. In this field of human activity the conditions are somewhat peculiar. The removal of the enormous logs brought down by the woodsman bristles with difficulties. The lumber-jack comes with the winter, when the ground is carpeted with snow two, three, or more feet in depth, and littered with huge drifts. Under such conditions ordinary systems of transportation are absolutely impracticable. Other industries which are isolated from the



ONE ENGINE OF THE ICE LOCOMOTIVE.
Showing inverted cylinders, and power transmission. A similar engine is mounted upon the opposite side of the frame.

A HEAVY LUMBER TRAIN.

A pilot sits on the front of the locomotive steering the leading runners by means of a wheel.

steel arteries of communication remedy such a defect by laying down a narrow gauge light line between their mills and the trunk roads. But in the lumbering districts of Canada and the United States such links of communication, even if provided, would be useless, as they would be snowed-up and impassable at the very time when traffic reaches its highest pressure.

The result is that in the lumbering trade horses and oxen play a very important part in hauling the timber from forest to mill, and from mill to railway. The logs, balks, boards, or what not, are piled on heavy sleds. But the movement is slow; the capacity of the train load is limited severely by the number and strength of the beasts available. Moreover, animal traction is expensive; difficulties arise in connection with foraging; while the cost of maintenance is just as heavy when traffic is at a standstill as during periods of activity, because the creatures must be fed, and well too, to keep them fit for their arduous labour.

Realising the shortcomings of animal transportation, the Phœnix Manufacturing Company of Eau Claire contrived a locomotive which could be run over an ice track as easily as its prototype can be driven over the steel highway. With infinite labour, and after innumerable peculiar problems had been solved, an engine was contrived and sent up into the forests of Wisconsin to prove its worth; to show how far it could compete with animal methods; and to determine the extent of its application.

The experiment was a complete success; steam haulage over the ice-way proved so superior to the animals that a demand for these locomotives arose on all sides. The development was opportune. The demand

for lumber was exceeding supply, and means of doubling and trebling the output with less expense were being sought diligently. The teams, as a rule, could not handle more than 1,500 feet of timber, even under the best conditions. Even then unremitting care had to be bestowed upon the roads, so as to keep them in the pink of condition to facilitate movement.

The ice locomotive revolutionised the situation. Bigger sleds could be built and loaded with three times as much lumber, while two or three such vehicles could be hitched to a single engine, which thus accomplished the work of 20 or 30 animals in half the time. The lumbering industries also discovered the significance of another item. The locomotive cost money only when it was performing useful service. When condemned to inactivity it did not "eat its head off," as was the case with the animals.

The future of the ice locomotive was assured; the firm responsible for the creation found itself overwhelmed with orders. The engine was improved extensively as a result of experience acquired under practical conditions, and to-day these locomotives are found in all parts of the country, hauling formidable trains of sleds, each laden with 15,000 feet or more of timber.

The boiler, of the locomotive type, designed for a steam pressure of 200 lbs. per square inch, is 15 feet long by 36 inches in diameter, and is mounted upon a heavy reinforced channel iron frame. There is a large fire-box, adapted to burn either coal or wood. It is an easy steamer, and economic in coal consumption—a vital factor seeing that coal invariably is a costly item in the lumbering districts. Similarity to the railway engine is enhanced by the cab provided for the driver and the fireman.

The engine is carried upon a leading "bogie" having a couple of massive

A BIG LOAD.
The size of the stacks of sawn timber mounted upon each sled may be gathered from comparison with the crew.

runners. On the front of the engine is a large wheel, with a seat, so that steering is carried out upon the broad lines of the automobile. The driving or traction device recalls the caterpillar tractor. There is a heavy iron shaft, 4½ inches in diameter, which carries on each side of the engine two weighty steel runners. A pair of massive boxes in which runs a heavy steel sprocket wheel is attached to each end of these runners. The sprockets mesh with, and carry, a tread or lag chain, 12 inches wide by 14 feet in length, which, securing a purchase upon the road surface, propels the locomotive. On the inner side of the chain-drive, and running in a steel channel attached to the underside of the steel shoe, are two roller chains. Each runner is fitted in this manner.

The Engine.

The engine has four cylinders of 6¼ inches diameter by 8 inch stroke, two cylinders being disposed on each side, and bolted to the boiler and frame. Each pair of engines is fitted with link motion. The power is transmitted from the engine to the driving chains through a spur pinion mounted on the crank shaft, and a pinion mounted on the front end of the driving shafts. Bevel pinions are attached to the rear ends of these driving shafts, and these mesh with large bevel gears carried on the ends of the fixed shaft or rear axles. They also have spur gears, which transmit the power through the intermediate gearing to another spur gear mounted on the shaft to which the rear sprocket is keyed, this being the driven sprocket.

Speed and Load.

The locomotive is built on heavy lines so as to be able to withstand hard work. The cab fittings are of the usual railway locomotive type, with quadrant and lever for reversing. In running order the engine weighs about 19 tons, and with the steam pressure at 200 lbs. about 100 horse-power is developed. The average speed is from 4 to 5 miles per hour over a good track, though of course this feature is governed by the severity of the grades, curvature, and the load. Here, as in railway practice, the easier the grade and the more open the curves, the higher the speed and the heavier the load hauled. Under good conditions an engine can draw a train of 15 vehicles loaded with 5,000 to 7,000 feet of logs per sled. The train crew comprises three men—the driver, fireman, and the pilot or steersman. So far as fuel consumption is concerned, from 1¼ to 1½ tons of good steam coal will suffice for a 10-hour run. Water facilities have to be provided at intervals of five or six miles, and if this commodity is scarce then a tank wagon on runners similar to a tender is attached to the engine.

The vehicles themselves vary according to the prevailing conditions. If circumstances permit of the laying of a wide road, a gauge of 7 or 8 feet can be used to distinct advantage. The load stowed thereon may range from 10,000 to 20,000 feet. In such cases the over-all width of the load at the base may easily represent 16 feet, the logs being held in position by chains passed round the whole and tightened up to keep the load steady.

Preparation of the Road.

Successful operation is governed by the care expended upon the preparation of the road. A good track with easy banks and curves eases the strain upon the locomotive very considerably. When the snow has packed well and frozen hard, an excellent surface is offered, and the careful distribution of water over this surface, converting it to the semblance of a sheet of glass, especially in the ruts, enables heavy loads and good speed to be maintained with the minimum of wear and tear.

The work which can be accomplished by these powerful locomotives is astonishing. They may be seen puffing and snorting in the dense forests of the Middle and Western States and the backwoods of Canada. The heart of the Canadian lumber industry of

AN ICE TRAIN AT FULL SPEED.

When the ice track is prepared carefully the train is able to make 8 miles an hour, with a load of 80,000 feet of lumber. On long journeys a water tank is attached to the engine.

Western Canada is around Prince Albert, where many of these little giants are at work. They may be seen toiling in a temperature ranging from 30 to 55 degrees below zero, drawing loads of 80,000 feet or more of green lumber over distances of 60 miles a day. Though the grades appear to be somewhat adverse, the train of seven sleds, large water tank, and caboose for the train crews, seems to make light of them. One lumbering firm in Minnesota, which has a 10-mile road, makes two round trips a day with a load of six vehicles, and accomplishes for £14, including an allowance of £3 per day for wear and tear, what would require 48 horses in twelve teams at a cost of £30.

At times these engines have to perform herculean work, especially when the country is swept by blizzards. Then the snow roads are buried beneath huge drifts, deep enough to swallow the engine. One firm had to hitch an improvised snow-plough to the engine, and for 16 miles the train and crew had a stiff fight for every yard of the way. They turned round and found the snow had drifted just as badly, completely obliterating the road once more. It was another tedious drive over the 16 miles on the homeward jaunt, but the train got through, and only an hour or so behind her usual time. Some idea of the significance of this performance may be judged from the fact that on the railways traversing the self-same country, double-headers had to be used to get through the drifts, and even then the trains were running from four to twelve hours late.

Some Good Records.

At another camp, the train comprising from 7 to 10 sleds, had to work continuously day and night over a track about 18 miles in length, the crews being changed at the end of each round trip. In this case the one engine did the work of 72 horses, and during the season handled 2,500,000 feet of pine, 100,000 posts, 3,000 railway sleepers, 200 cords of pulp-wood, and some 50 sled-loads of provisions and other stock. The greatest difficulty that the lumbering interests experience in connection with these locomotives and trains is in regard to loading up. Not only are heavy delays incurred from this cause, owing to the scarcity of labour, but often the train has to start off with a lighter load than she could haul with ease.

One Engine =72 Horses.

Although this ice locomotive is virtually an asset of and peculiar to the North American continent, it has made its début in Europe. An ice track has been laid down in Finland, and one of these imported engines has been put to work. This experiment is being followed closely by European interests, inasmuch as there is remarkable scope for such a system of transportation throughout the timber stretches of Russia and Siberia, where lumbering as an industry has achieved a higher stage of development than in the New World.

THE FLOODING OF THE SEVERN TUNNEL.

Owing to the water breaking into and flooding the workings, boring was brought to a standstill until Diver Lambert volunteered to penetrate the heading to close a heavy door isolating the affected section, in which daring task he was successful.

Photograph supplied by the Great Western Railway Co.

ONE OF BRUNEL'S TIMBER VIADUCTS IN CORNWALL, SINCE REPLACED IN STEEL.

The Great Western Railway

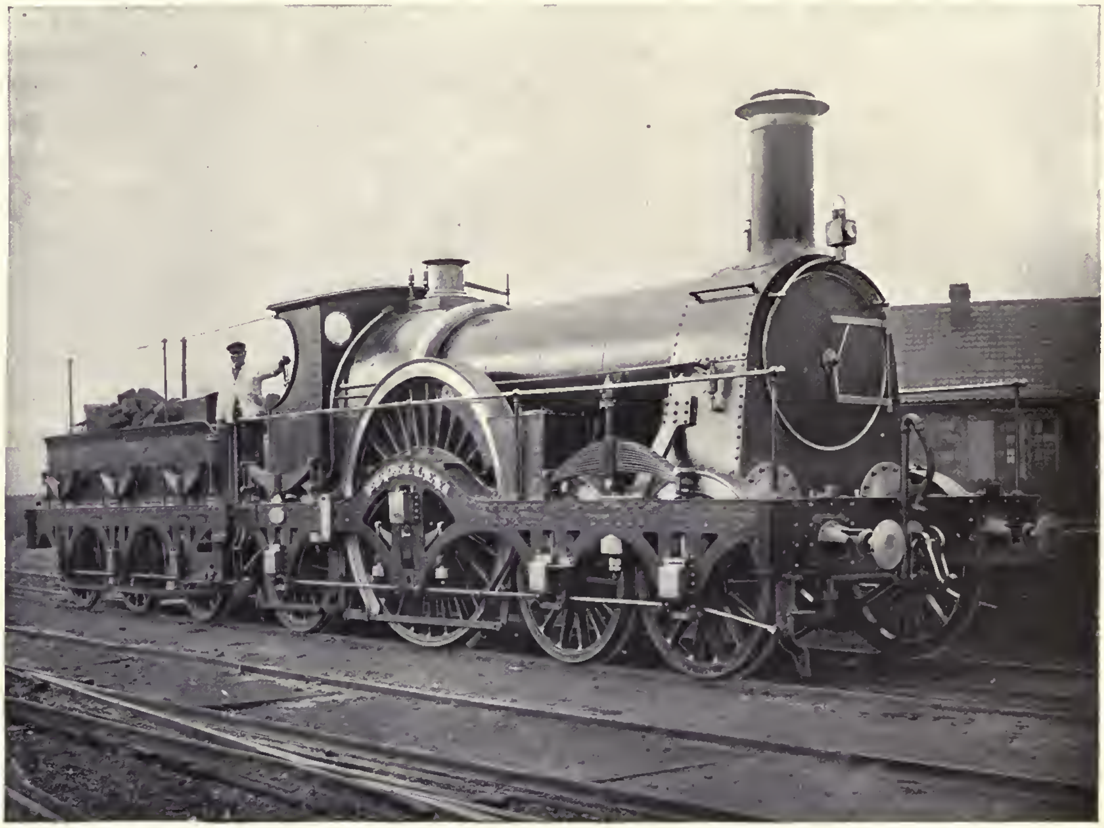
THE STORY OF BRUNEL'S GREAT ENGINEERING FEATS IN LINKING UP LONDON AND THE WEST

IT was the success of the Liverpool and Manchester Railway which was responsible for the projection of a means of connecting Bristol to London by the steel highway, as a faster alternative way of communication to the circuitous canal route then in vogue. Directly the suggestion came before the public it received the inevitable hostile criticism, because the projectors were treading on the toes of scores of other interests, who viewed the Stephenson invention with undisguised disfavour.

The scheme languished for many years, until at last in 1832 a strong influential committee was formed to carry the idea into effect. This commercial body knew nothing about the technical problems involved, and they cast about for an engineer. Among the aspirants was that engineering genius Isambard Kingdom Brunel, then only twenty-seven years of age. Although young, he had already carved out a unique reputation, and he carried the day; and became the first engineer of the Great Western Railway.

Although the promoters only intended to connect London with Bristol, they failed to secure the necessary support. Accordingly they decided to construct the line piecemeal, so that when the first application was made to Parliament it was for two pieces of line running respectively from London to Reading, 36 miles, and from Bristol to Bath, about 10 miles.

The interests supporting the scheme concluded that if these wedges were driven home it would be an easy matter to span the intervening gap of 72 miles. Even then they experienced a stiff uphill fight owing to the strength of opposing vested interests, so that it was not until August 31st, 1835, that King William IV. appended his signature to the London and Bristol Railway Bill.



Photograph supplied by the Great Western Railway Co.

A FAMOUS "FLYER" OF THE BROAD GAUGE ERA.

In his constructional work Brunel was harassed by some of his controlling associates. He did not progress so rapidly as they desired. On more than one occasion he was within an ace of being superseded; proposals to bring in George Stephenson to straighten matters out were made frequently. When the line was opened it proved sadly lacking in many constructional respects, and there is no doubt but that for the unswerving support extended by one or two of the directors, the young engineer's connection with the railway would have terminated abruptly.

As events proved, Brunel made a big blunder in the very beginning. Stephenson had adopted what is known now as the standard gauge, viz. a width of 4 feet $8\frac{1}{2}$ inches from centre to centre of each pair of rails. This has been designated as a clumsy, haphazard decision, but Stephenson appears to have been content with what satisfied the world as he found it. The existing vehicles using the high roads, lanes, and tramways of the mines in the north had a certain gauge. Stephenson naturally carried out his experiments on this gauge, which eventually came to be adopted for the railways built shortly after his invention had proved its worth. The standard gauge often has been assailed as too narrow, but the mistake was not

Stephenson's by any means. He merely adapted his radical revolution to existing ideas.

On the other hand, Brunel considered this gauge unsuited to high speed, carrying capacity, and safety. So he elaborated a gauge of his own, 7 feet, 0¼ inches, and strangely enough this was adopted for the Great Western. Certainly he justified his contentions, but they afforded no argument.

The "Battle of the Gauges."

There is no doubt that Brunel was supported in his gauge ideas by the desire to create a monopoly for the Great Western. In the early days of railway building the country was divided off into zones, and the concerns interested in railway transportation agreed to respect certain boundaries. Interchange of traffic was the last thought entertained—at least, by Brunel, though it was foreseen by Stephenson and others. The "Battle of the Gauges" was waged keenly in Great Britain, but the narrower gauge won, the Great Western Railway had to bow to the inevitable, and was forced to the Stephenson gauge, although the change was not effected until 1892. By means of a third rail to standard guage inter-working had, however, been practised for some time.

Brunel's Great Grade.

But if Brunel proved to be in error in regard to the question of gauge, he was far more perspicacious concerning the overwhelming advantage possessed by the straight level line. In running the surveys he kept down banks and avoided sharp curvature. The advantage of this is shown to-day. True, overhaul has been necessary, but it has not involved wholesale revision and reconstruction of the road, as has been the case in other parts of the world. The Great Western now is practically as Brunel left it concerning location; it merely has been improved in accordance with the marches of railway progress. Brunel aimed at high speeds, and big running performances, which explains why the Great Western Railway is one of the finest and fastest railway galloping grounds in the world, enabling trains to run the 118 miles between London and Bristol in 120 minutes, as well as the establishment of the longest and quickest non-stop runs—143 miles to Taunton in 150 minutes; 174 miles to Exeter in 180 minutes; and 225¾ miles to Plymouth in 247 minutes.

The first 23 miles of the railway out of London were completed to Maidenhead in 1838. It was a badly-built stretch of track, and the public were loud in their complaint concerning oscillation and jolting. The question to decide was how much was due to the permanent way and how much to the rolling stock. Under the weight of the trains the track went all to pieces within a very short time. Brunel, with characteristic courage, acknowledged that the road was in a bad state and divined two reasons for its break-up—insufficient ballasting, or the use of fine instead of coarse gravel. The logical solution was attempted. Two half-mile stretches of track were ballasted upon divergent lines to test the respective values of each method.

Quaint Opposition.

The following instances afford some idea of the quaint opposition which railway projects received in those days: The town of Maidenhead rose up in arms against the railway because it approached their boundaries too closely. On the other hand, Windsor became fiercely hostile because it left them too far to one side. Eton College regarded the line with deep-rooted objection, and brought an action to prevent the railway establishing a station at Slough. This effort received the scant consideration it deserved; it was dismissed. A little later the self-same authorities requested the company to provide a train at the disputed stopping-place in order to convey the boys to London. Some of the farmers adjoining the right of way grew apprehensive that the smoke would suffocate their live stock, while residents firmly

believed that they would be driven frantic by the noise of the passing trains.

The River Thames offered the first serious obstacle to the western advance of the railway. At this point the river is some 207 feet in width, and divided near the centre by a shoal. As the banks are somewhat low, and the gradient is maintained on either side, Brunel was somewhat hampered in his design so as to not encroach too much upon the headroom for navigation. He decided to introduce two main spans, each of 128 feet, and with a very flat elliptical arch. Brick was selected, and the work ranks as one of the largest structures of its kind ever attempted in this constructional material. Its erection, however, was not free from incident. The contractor, no doubt harried somewhat by the powers above, took away the centres too soon, with the result that a deformation set in. The administration, after Brunel had made an inspection, held the contractor responsible for the damage, and compelled him to repair it. In the meantime the most extraordinary stories relative to the incident had been circulated, and it was only with difficulty that the anxiety of the shareholders was allayed.

Photograph supplied by the Great Western Railway Co.

SLIPPING TWO COACHES OFF THE UP AMERICAN MAIL WHILE TRAVELLING AT 60 MILES PER HOUR.

By March, 1840, the original proposal was completed; the line was opened to Reading, and in the same year the Bristol to Bath section was finished. Without any delay the line was continued from each end so as to close the gap in the communication between Bristol and London. Going westwards little difficulty was experienced, inasmuch as the country threaded is fairly level, but coming eastwards from Bath the 13 miles were somewhat heavy, involving the introduction of two steep banks of 1 in 100—the Wootton Bassett and the Box—on

which a "double header" or a "pusher" engine had to be used for several years. In this section the engineer also had to drive the Box Tunnel, 3,212 yards in length, which, however, did not prove a very difficult undertaking, owing to the regular character of the rock encountered, although it occupied some time. At last, on June 30th, 1841, the original project was realised; the London and Bristol Railway was opened.

Photograph supplied by Great Western Railway.

THE AMERICAN BOAT EXPRESS LEAVING FISHGUARD FOR LONDON.

The original line, forming the basis of the Great Western Railway, always has been famous for the high running speeds attained thereon. Certainly the location and alignment are conducive to this result. Between the two points the railway only has to rise to a matter of 270 feet above the metropolis, and then drop 292 feet into Bristol. Of the 118 miles no less than 67 either are level or rise only 4 feet per mile, while another 47 miles have grades ranging between 4 and 8 feet per mile. The remaining section is made up of the two short banks, rising 1 in 100, against eastbound traffic.

As may be supposed, while this railway was under construction, further lines in conjunction therewith were projected and carried into effect. An obvious extension was from Bristol to Exeter, built by another company and opened in 1844. In due course came the South Devon and Cornwall lines. The various sections being in connection, it was possible to travel by rail from London to Plymouth and beyond. When the Great Western Railway had become firmly established, a policy of absorption was followed, so that slowly but surely innumerable short links were bought up and amalgamated with the parent concern. Under this policy the company became entrenched firmly throughout the south-west and west of England.

Through railway travelling between London and Cornwall was broken at Plymouth by the broad Tamar, which at this point is 1,100 feet wide, with a depth of 80 feet at high water. At first the obstacle appeared to be so formidable that a steam ferry was projected, but at last it was realised that a bridge was the true link of communication, and a point at Saltash was selected for the crossing. A design was prepared, to be executed in timber, having one span of 225 feet, and six spans each of 105 feet. Doubtless this project would have been undertaken had the Government not interfered. Devonport

naval base is close by, and the Admiralty insisted that the waterway should be kept clear, that at least 100 feet of headway should be provided, and that there should be only five spans.

Faced with this irreducible minimum Brunel evolved a startling design. The bed of the Tamar is somewhat unstable, and the building of piers in deep water always is a costly and tedious proceeding. Brunel boldly decided to introduce only two main spans, thereby reducing sub-aqueous work to one pier in the channel. This entailed two big spans, each of 455 feet. The foundations and under-water operations upon the central pier offered the most perplexing problem, however, owing to the great depth of water.

After considerable reflection the engineer decided to build the pier upon the caisson system, although it involved a huge structure and operations upon a scale which never had been attempted up to this time. The massive cylinder was 95 feet in length by 35 feet in diameter. In this cylinder a diving bell was improvised, about 20 feet above the lower end, and from the centre of this extended a smaller tube 10 feet in diameter. Inside the diving bell was placed another cylinder, 27 feet in diameter, divided vertically into 11 compartments, each of which was kept dry by compressed air. In this way the compressed air working space was confined to a ring of compartments, instead of the whole area beneath the dome. The air-lock was placed on top of a tube 6 feet in diameter, set to one side of the central 10-feet tube. Some difficulty was experienced in sinking the cumbersome caisson in the desired position, owing to the configuration of the river bed. Once it tilted alarmingly, but was righted, and then settled down in the designed vertical position. In the course of some eight months it was sunk to the solid rock, the bottom edge being 87½ feet below high water.

Photograph supplied by Great Western Railway.

A LOCOMOTIVE GRAVEYARD—BROAD GAUGE ENGINES AT SWINDON STATION, MAY, 1892.
Withdrawn from service by the conversion of the gauge from 6 feet to 4 feet 8½ inches.

Once the caisson was bedded the substructure proceeded rapidly. The masons set the ashlar granite masonry in the compressed air compartments, the material within the core was removed and filled up, the inner caisson removed, together with the diving bell, and lastly the outer cylinder was dismantled. By the end of 1856 the pier had been brought to a height of 12 feet above the water, and the most searching and anxious part of the task was completed.

While the subaqueous work was in progress the two huge spans were taken in hand. They are of unusual design, comprising a combination of the tubular and suspension bridge principles. The top member of the truss is an arched elliptical tube, $16\frac{3}{4}$ feet wide, $12\frac{1}{4}$ feet deep, by 460 feet in length, carried out in wrought iron. From end to end on each side there are heavy suspension chains. At eleven points, on each side of the tube, are vertical struts, braced by diagonal ties, whereby the chains are connected to the tube. The track floor is a horizontal girder suspended from the truss, the depth of the latter in the centre being 56 feet. When completed each span weighed 1,060 tons.

Measurements of the Spans.

These spans were built on the Devonshire shore, and the method adopted for their transference to the site and placing in position was distinctly ingenious. A dock was excavated under each end of the span, into which pontoons were floated at low tide. On the deck of each pontoon a massive timber staging was built to receive the end of the truss. When the water rose it lifted the pontoon and the span, until at last the steel was supported entirely on the pontoons. The mass of steel was floated out into the river and warped into position between the central and the shore piers. Five vessels were stationed in the river for this purpose, and by cable and capstan the floating deadweight was brought into place. In this work alone some 500 men were requisitioned under the personal supervision of Brunel. Water was admitted into the pontoons, causing then to sink, when they were drawn clear, leaving the ends of the span resting upon the bases of the piers.

How the Spans were Raised.

The truss itself was lifted gradually as the masonry work on the piers proceeded. Three hydraulic presses were placed under each end of the truss, and at a given signal the structure was lifted about 3 feet. The masons then built up the pier in the under space, when the steel was lifted once more. By this novel lifting and building alternately the iron work was raised to its designed height. When the first span was completed the second was taken in hand and the cycle of operations was repeated. On this occasion, however, Brunel was unable to direct operations, having been stricken down by illness.

The bridge was completed, and opened by the Prince Consort, after whom it is named, on May 3rd, 1859. Its total length, including the viaduct approaches on each bank, is 2,200 feet, the rails being laid at 110 feet above high water. It carries a single track, Brunel having decided that thereby £100,000 might be saved in first cost. This was a vital consideration in those days, and needless to say was adopted with alacrity. Although the line on either side is double, no serious inconvenience ever has been experienced in working over this short length of single track. Its total cost was £225,000. This was the last big work carried out by the master-mind, and, helpless on a couch, he was drawn across the bridge upon its completion, to see his creation for the first and last time.

Cost £225,000.

Previous to the construction of the Saltash Bridge Brunel had accomplished some remarkably striking feats in carrying the railway through rugged Cornwall. The broken character of the country, and the lack of funds, compelled him to introduce some stiff gradients and sharp curves. Still, the most noticeable features of this

The Cornish Viaducts.

Photograph by Poulton & Son, Lee, S.E.

THE ROYAL ALBERT BRIDGE AT SALTASH WHICH CARRIES THE RAILWAY ACROSS THE TAMAR.

line were the timber viaducts, spanning the deep ravines. Some of these structures were of formidable proportions, the Landore Viaduct, for instance, being 1,760 feet in length, comprising 37 openings varying from 40 to 100 feet, while the St. Pinnock Viaduct brought the rail level 163 feet above the floor of the valley. The Walkham Viaduct of fifteen spans was 1,100 feet from end to end, and in the highest part 132 feet above the bottom of the rift. Wood was utilised as a constructional material to save expense, and the design comprised timber towers erected on masonry piers, with the deck carried on fan-shaped trusses. So substantial were these structures that on the early American railroads Brunel's design was followed, and it is only during later years that the present form of timber trestling has been adopted.

In revising and modernising the Cornish line the Great Western Railway replaced the timber structures by masonry and steel. Seeing that over sixty structures had to be replaced in this manner some idea of the magnitude of this modernisation work may be gained. Re-erection was carried out with very slight dislocation of traffic, although in the case of the Landore Viaduct the difficulties encountered were so peculiar it was feared that reconstruction under traffic conditions would be impossible. But an English engineer undertook the responsible task and completed it successfully without a hitch. Whereas the old timber viaducts carried only a single line, the new bridges have a double road, so that the Cornish railway has been brought into conformity with the remainder of the Great Western Railway.

But possibly the greatest engineering work associated with the Great Western Railway is the link whereby through railway communication is effected between the English and Welsh banks of the River Severn. In 1857 a company was incorporated, under the title of the Bristol and South Wales Union Railway, to run a line from Bristol into the Principality, the

interruption of $2\frac{1}{2}$ miles wide offered by the waterway being overcome by a steam ferry. In 1868 the Great Western acquired this railway, but the water-break was found to be a serious handicap to traffic. Accordingly parliamentary powers were sought, and obtained in 1872, authorising a tunnel beneath the river, upon which the railway company started in March, 1873, with Mr. Charles Richardson, a pupil of Brunel, in charge of the works.

The designs called for a double track bore 7,664 yards in length, with approaches rising 1 in 90 on the English and 1 in 100 on the Welsh shores respectively, between New Passage and Portskewet, although the river is only some $2\frac{1}{4}$ miles wide at this point. It was necessary to dip down somewhat deeply in order to clear the hollows in the bed of the river, one such depression, known as the "Shoots," half-a-mile from the west shore, having a depth of about 100 feet at high water. According to the plans a depth of 30 feet was provided between the water and the crown of the tunnel.

Trouble with water was anticipated, owing to the geological formation comprising shale, sandstones and marl, but even the worst anticipations were exceeded eventually

The Great Western Railway undertook the task and prosecuted it sedulously for six and a half years. On October 16th, 1879, there was a terrific water-burst. A spring let loose a stream of water, 7 feet in width by over 12 inches deep, which poured down the steep driftway like a mill-race and flooded the whole of the works when the driftways, driven from the opposite banks, were within 130 yards of each other.

All efforts to cope with the inundation with the existing pumping plant proved

Photograph supplied by Great Western Railway.

LOOKING THROUGH THE ROYAL ALBERT BRIDGE, SALTASH.

The total length, including approaches, is 2,200 feet, and the single track is 110 feet above high water.

fruitless, so that work was brought to a standstill. The expert assistance of Sir John Hawkshaw, who had been consulting engineer up to this point, was called in, and he instantly recommended drastic expedients which were beyond the railway company. Thereupon the latter decided to withdraw from the undertaking, to place the whole responsibility upon Sir John Hawkshaw, and to let the work to contract. Mr. T. A. Walker, the well-known constructional engineer, secured the enterprise, and steps at once were taken to check the flow of water.

Diver Lambert's Success.

Heavy oak shields were built and lowered into the water to be attached to the sides of the driftways, fitted with massive doors, so as to divide the bore into sections. One doorway was placed beneath the river itself, 330 yards from the shaft, and time after time divers descended to close this portal, but in vain. They were forced to retreat on every occasion. Finally, Diver Lambert, one of the most expert of submarine toilers, volunteered to attempt the task, notwithstanding its dangerous character. He donned a Fleuss dress, wherein the diver carries his air supply with him, thereby dispensing with the long trail of air-pipe which had frustrated all efforts hitherto. He started off, and for 85 minutes nothing was heard of him. Had he failed; had the supply of respiratory air given out and left him unconscious in the flooded bore? It was an anxious time to those above; they realised the gravity of the task confronting the intrepid diver, who was forced to stumble through a rough, uneven passage under the river. Just as speculation concerning his safety had risen to fever point he was discerned returning. He had closed the door and the water was held up. In the meantime another door had been placed across the heading down which the water was rushing. Directly this was closed the inflow was dammed back.

Denuded Springs.

When the water-burst occurred several springs and wells in the vicinity dried up, while the River Nedern shrank to a brook, thus testifying only too palpably that the water which normally fed them was finding another outlet. Directly Lambert had closed the door the springs and wells returned to life, while the Nedern resumed its normal level.

Tunnel Flooded for Three Years.

Meanwhile Sir John Hawkshaw, having been appointed chief engineer, had revised the plans. He lowered the tunnel by 15 feet, thereby increasing the depth between the roof and the river bed to 45 feet. No attempt to remove the water held back by the door was made until 3½ years later, during which time a new pumping shaft was sunk. When the water was cleared out it was found that a part of the roof had fallen in behind the door, leaving a cavity 40 feet in height. The pumps were kept going removing the 6,000 gallons of water which poured in every minute, and the debris was cleared away.

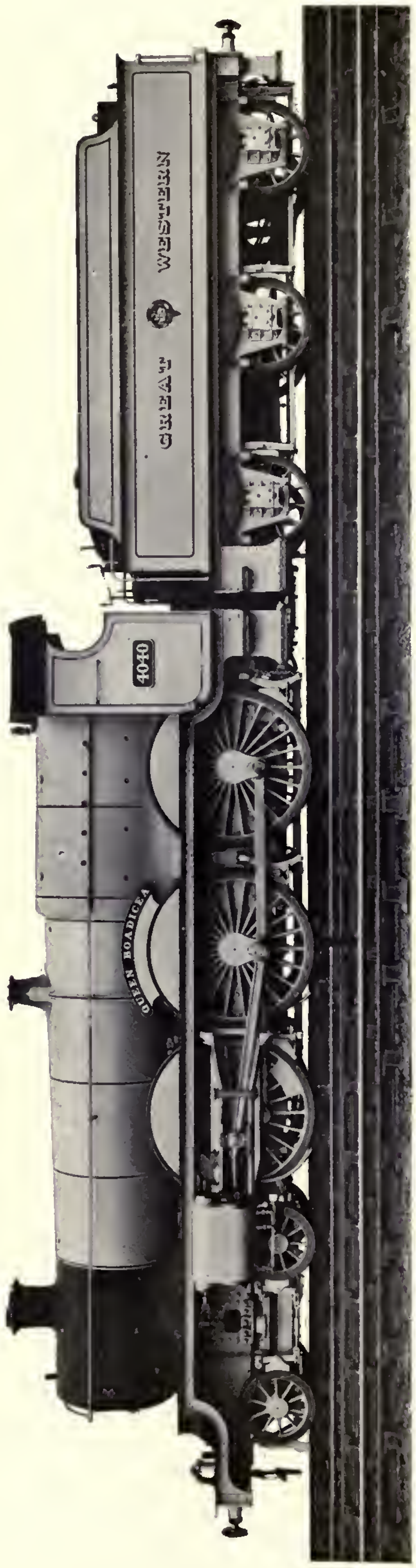
A Second Flooding.

As the level of the tunnel had been lowered, a new driftway was driven below the old one, so that what was originally the bottom heading now became the upper one. The water was kept down completely until the borers had penetrated to a point about 100 yards beyond the door which Lambert had closed, where the first water-burst was encountered. Then came another dramatic inundation. Whereas in the first instance the water had entered from the side and roof, in this instance it burst up from the bottom, and in such volume that the works were filled up to a level of 95 feet in fifty-one hours. The inrush was so sudden that three out of the seven men working at the spot were overwhelmed and drowned. It was estimated that the water entered the workings at the rate of 27,000 gallons per minute, while as the pumps could only cope with

Photograph supplied by Great Western Railway.

ERECTING ONE OF THE MAIN SPANS OF THE ROYAL ALBERT BRIDGE, SALTASH.

The mass of wrought iron, 460 feet in length, weighed 1,060 tons. It was floated out to the site on pontoons and lifted 3 feet at a time by jacks as the masonry piers were built up to the designed level.



Photograph supplied by Great Western Railway.

THE "QUEEN BOADICEA," OF THE 4-6-0 CLASS, DESIGNED FOR THE HEAVIEST AND FASTEST EXPRESS SERVICE.

11,000 gallons per minute, they were overtaxed hopelessly. But they were kept going incessantly night and day for three weeks, and gradually reduced the level of the water, but the struggle for mastery was a stern one, the gain not exceeding 7 inches in the course of 24 hours.

The new driftway, like the old, had been fitted with doors as a precaution, but whereas the men closed the upper one in their rush, the lower door could not be pushed against the water pressure. Before anything could be done it was essential that this door should be closed. It demanded a diver, and he had a crawl of 150 yards to the spot from the bottom of the shaft. Again Diver Lambert came to the rescue. In an ordinary diving suit, and with the assistance of two comrades, one standing at the bottom of the shaft and another about 75 yards along the tunnel to manipulate his air pipe, he succeeded in reaching and closing the door.

When this was accomplished the level of the water was reduced speedily, and as soon as the tunnel could be entered a massive wall, 15 feet in thickness, was thrown up across the bore 88 yards from the shaft. This was equipped with a heavy iron door, together with sluices, and directly the pumping machinery had been increased, so as to lift 27,000 gallons of water per minute, the flooded area was cleared. It was found in this instance that the incoming water had torn a huge hole in the floor of the driftway. This was filled with clay puddle, and covered with a mound of the same material in bags. Subsequently this mound was levelled off and covered with concrete. A little farther on another fall of the roof was found. This was a fortunate discovery, as otherwise another inundation would have resulted. This disaster was avoided by timbering up the roof with all speed, and finally bricking it in cement when the tunnel lining advanced.

The tunnel is of semicircular arch section,

with a diameter of 26 feet inside the lining, and a headway of 20 feet in the centre. A permanent pumping plant was installed on the Welsh side, together with a ventilating system. The pumps are capable of meeting any demand that is likely to be made upon them by the spring which caused so much trouble in the early days, so that now no water finds its way into the bore, the spring emptying into and being removed from the shaft provided for the purpose.

The tunnel was opened for goods traffic in September, 1886, after some 13½ years' labour. When work was in full swing over 4,000 men found employment. Although longer tunnels have been bored in other parts of the world, few have offered such perplexing and peculiar difficulties as were encountered under the Severn. Passengers first travelled by railway under the waterway on December 1st, 1886, and to-day it is a busy artery, seeing that it constitutes the shortest and most direct route between London, Bristol, and South Wales.

The last great enterprise which the Great Western Railway took in hand was the construction of Fishguard Harbour, together with the railway connection therewith. In reality this was only a revival of a scheme projected as far back as 1845. Brunel realised that Fishguard was the strategical point for the south of Ireland and Atlantic traffic, and commenced to provide a harbour, together with railway facilities, but funds giving out, the scheme had to be abandoned in favour of New Milford, which offered an excellent natural harbour. When the engineers came along half-a-century later they found traces of Brunel's work on every hand as well as some miles of the rusting derelict railway which the master engineer laid down. His grades, running up to 1 in 27, however, were too steep, so a new and more level line was fashioned with no banks heavier than 1 in 100. By this means the Welsh port was brought within 262 miles of London over a line adapted to fast travelling, which has been demonstrated convincingly since the incoming Cunard liners dropped their American mails and passengers at this point.

While the original London and Bristol line has been brought to a high state of efficiency, and enables passengers to cover the 118 miles between the two points in 120 minutes, a new route for western points has been laid parallel to the parent road, though some miles to the south, between Reading and Taunton. In this way the old line via Bristol has been relieved of a considerable volume of traffic. A fast through line has been provided also between London and Birmingham, as well as other important points in the western midlands.

To-day the system embraces 3,000 miles of road over which travel considerably more than 100,000,000 people every year. The Great Western Railway ranks at present as one of the most substantial, fastest, and smoothest travelling lines in the world, while its long distance expresses stand supreme in point of speed, comfort, and luxury.

Photograph by permission of Swan, Hunter, and Wigham-Richardson, Ltd

BROADSIDE VIEW OF THE *DROTTNING VICTORIA* AT SEA.

This boat plies between Sassnitz (Germany) and Trelleborg (Sweden), a sea passage of 65 miles.

Floating Railways—II

THE GIGANTIC FERRIES OF EUROPE AND ASIA

DESPITE the high standard to which the railway ferry has attained in the United States and Canada, one must come to Europe to see its most imposing development from the all-round point of view. In fact, the latter services of this character are superior in size, speed and luxury. The Danish Government has several floating railways in operation, the longest route being between Gjedser and Warnemunde, a distance of 26 miles. But the pre-eminent European service is that in operation between Sassnitz, on the German seaboard, and Terlleborg, in Sweden, as the vessels have to traverse 65 miles of the Baltic Sea, with its treacherous currents, tides, storms and ice. When the elements are in torment the seas are particularly heavy.

This ferry service was brought into operation by the German and Swedish Governments at an outlay of nearly £1,000,000, the respective countries contributing two vessels each to the fleet. The two German boats were built in that country: one of the Swedish craft was constructed in Sweden, while the other, *Drottning Victoria*, was furnished by Swan, Hunter, and Wigham-Richardson, Limited, of Wallsend-on-

Tyne. As the four vessels are practically identical, a description of the broad features of the British-built vessel will suffice for all. The *Drottning Victoria* has an over-all length of 370 feet, beam $53\frac{1}{2}$ feet, draught loaded $16\frac{1}{2}$ feet, displacement 4,270 tons, and a maximum speed on service of $16\frac{1}{2}$ knots—about $19\frac{1}{2}$ miles per hour—this being adequate to enable the sea journey of 65 miles to be covered within four hours.

The main deck carries two sets of metals, which are sufficient to receive eight bogie passenger-coaches in two parallel rows, each 295 feet in length. The cars are run upon the vessel over a special bridge. To accommodate the variations in the level of the tracks owing to tidal influences, a system of trimming tanks is brought into action to maintain the trim of the vessel during the operation. The car deck is so designed as to be able to receive coaches measuring $15\frac{1}{4}$ feet in height, by a width of 11 feet 2 inches — the maximum dimensions permitted by the respective State railway systems.

The arrangements for securing the coaches

Photograph by permission of Swan, Hunter, and Wigham-Richardson, Ltd.

STERN VIEW OF THE *DROTTNING VICTORIA*.

Showing the car deck and berthing arrangements.

Photograph by permission of Swan, Hunter, and Wigham-Richardson, Ltd.

CAR DECK OF THE *DROTTNING VICTORIA* LOOKING AFT.

Showing screws whereby the train is secured to shackles in the floor, and jacks, which placed beneath the axles of the coach relieve the springs.

are interesting. Along the deck heavy shackles are fitted both inside and outside the track. The former are spaced 4 feet 4 inches apart, while the latter are placed at intervals of 8 feet 8 inches. Specially designed screws are attached to these deck plates and shackles provided on the coach frame, to hold the coach absolutely rigid. But, as an extra precaution during heavy weather, additional similar screws are introduced between the top of the car and the deck girders on each side, thereby protecting the superstructure of the coach from swaying motions. In order to relieve the strain upon the car springs during transit heavy jacks are placed beneath the carriages and extended just sufficiently to lift the coach-body off the wheels.

The ferry is equipped with magnificent accommodation for the comfort of the passengers, the appointments being carried out upon the most liberal lines, so that the craft is both a ferry and steamship in one. Indeed, an atmosphere of luxury such as is seldom approached upon cross-channel mail-boats is presented, there being dining and smoking saloons, lounge, drawing-rooms, and regal apartments on the promenade deck; below the car deck is the state-room accommodation for 96 first-class and 45 third-class passengers.

As the ferries make the crossing at night, many passengers do not wish to forsake their sleeping quarters in the train, and yet desire the conveniences concerning heat and attention incidental to modern travel. The steam heating facilities of the train, therefore, are coupled to the ship's heating system by a connection at the buffer stops, while electric-bell connection with

the stewards on board is effected at the same point.

The vessel herself conforms in every respect with the latest ideas in ship-building. The hull is freely subdivided into watertight compartments, fitted with Stone-Lloyd watertight doors. Two large searchlights are carried, one forward and one aft, to facilitate entrance into the terminals, and a bow as well as a stern rudder is fitted. The former is used in conjunction with the latter only when travelling astern, as when backing into the dock, since the trains are run on and off at the stern. At other times the forward rudder, which virtually forms part of the stem of the vessel, is locked by a bolt in the neutral position.

In addition to the passenger and crew accommodation, facilities are also provided for housing the Customs staff, the railway officials, and the Postal department. The Customs officials perform their duties during the journey, while simultaneously the sorting of the mails progresses. It is admitted that, from the point of comfort and luxury, these railway ferries have no equal, while they represent a decided advance upon American practice so far as the ship-building craft is concerned. Each boat cost about £115,000, so that the outlay on the fleet was approximately half-a-million sterling. The *Drottning Victoria* on her official trials easily exceeded the contract speed, while in service her sea-going qualities have not failed to arouse widespread attention among travellers frequenting this route.

When the Russian Transcontinental Railway was driven across the steppes of

Photograph by permission of Swan, Hunter, and Wigham-Richardson, Ltd.

FIRST-CLASS SMOKING ROOM OF THE *DROTTNING VICTORIA*.

This boat is luxuriously furnished.

Siberia, the advance of the engineers was disputed by Lake Baikal. The first proposal was to swing around the southern end of the lake, but the country was so forbiddingly mountainous, and the work of the engineers was certain to be so slow and tedious, that, in order to secure through railway communication with the East, it was decided to establish a floating railway section upon this inland sea. This was a somewhat startling proposal, seeing that the lake during the winter is completely and thickly frozen over, the low prevailing temperature keeping it firmly locked in this condition for about half the year. Thus it seemed at first sight as if the ferry service would have to be restricted to the summer months only, unless an icebreaker were provided as well, so as to plough the channel for the ferry. Thereupon a combination of the two types of vessels was evolved.

The contract for this ice-breaking ferry was awarded by the Russian Government to Sir W. G. Armstrong, Whitworth and Company. A special design was elaborated, the lines being of such a character as to offer the least resistance to the ice, and yet at the same time to present the maximum smashing effect. The *Lake Baikal,* as she is called, is somewhat unique, and probably represents one of the strongest ships that ever has been built. She measures 290 feet in length by 57 feet in width, and under normal working conditions draws 18½ feet of water. The hull is built throughout of steel, closely subdivided into watertight compartments, the result being that several compartments must be pierced before the safety of the vessel is imperilled, while the provision of a double bottom ensures greater security. In addition, there is a belt of 1-inch steel, 9 feet wide, extending from stem to stern at the waterline. The cars are run on to the main deck, and are secured by special devices to hold them steady during the journey of some 40 miles from bank to bank. The vessel is fitted with three screws, two at the stern, as usual, and one at the bow.

THE FERRY STEAMER *LAKE BAIKAL.*
It plies across Lake Baikal, in connection with the trans-Siberian Railway. It is an ice-breaker as well.

One of the most interesting features in connection with this craft was the fact that she had to be sent in pieces from the Tyne to the distant inland sea. To divide and pack up a vessel weighing 4,200 tons in

this manner was no light task. The dismembered ferry was shipped in a steamer to St. Petersburg, where the load was transferred to railway trains and dispatched to the railhead in Siberia, which at the time was some distance from the lake shore. There the packages were transferred to sledges and hauled by horses over the snow-covered steppes to the water-side, where the parts, as they arrived, were reassembled, and the vessel in due course consigned to the bosom of the lake.

The ferry has given complete satisfaction, and has demonstrated her capacity to cope with the thickest and heaviest ice peculiar to this lake. The cars being run on at the stern and made fast, and the signal given to go ahead, the vessel steams slowly out of her dock. The nose of the vessel, owing to its peculiar shape, does not cut into the ice, but lifts as with a glancing blow, until it rests upon the surface. Simultaneously, the front screw in its revolutions displaces the water beneath the ice, so that the full weight and force of the hull press down heavily. The ice has to give way, being broken into huge masses, which are flung hither and thither in the open channel behind by the ferry's wash. Although the railway since has been completed around the end of the lake, giving continuous railway communication, the floating section is still in operation, as the trip across the lake saves considerable time, and is accordingly used for the through fast mail traffic. The *Lake Baikal* has been in constant use since 1897, and even after some fifteen years' battling with the winter and ice on this inland sea is as efficient as ever. It is a moot point, in view of the *Lake Baikal's* achievements, whether the ferry ever will disappear from the trans-Siberian railway service. It is more probable that, as the traffic develops, the system will be extended.

Another novel and large ferry steamer was built in 1895 by the creators of the *Lake Baikal* for service upon the River Volga, where some very arduous work has to be fulfilled. Not only is the current very swift, but the river rises and falls to a remarkable degree according to the season, the difference in level between winter and summer being no less than 45 feet. Under these conditions, a somewhat novel idea had to be incorporated.

The steamer is 252 feet long, by 55½ feet wide. On her decks four tracks are laid—converging into two at the fore end—capable of receiving twenty-four trucks. On the banks the rails are brought to the water's edge by two levels, one being disposed 20 feet above the other. The latter is used when the river is low and the upper when it is in flood. But even in the first named instance there is a difference of 25 feet to overcome under the most disadvantageous conditions. This is met by the provision of a hoist in the front part of the vessel, which is operated hydraulically. This hoist carries two cradles, which when lowered are flush with the deck. In loading, the cars, are run on to one of the bank landing-stages, and by means of a capstan are warped on to the cradle, to be lowered to the deck. In unloading the operation is reversed. While the method is somewhat involved as compared with the previous systems of train ferry, where the vehicles are run straight on and off the deck tracks, it offered the only solution of the peculiar conditions associated with the River Volga.

The railway ferry undoubtedly constitutes one of the most interesting features of railway operation. Seeing that the system is so successful in all parts of the world, the question may well be asked why it has not been adopted for the maintenance of through railway communication between England and France? In every instance where the idea has been introduced a wonderful increase in the volume of traffic has resulted, so that the floating railway possesses a far-reaching economic value.

TYPICAL MOUNTAIN COUNTRY IN THE YUNNAN PROVINCE.
Showing the track on either side of the Faux Nam-ti Gorge. The bridge is seen in the distance

The Railway in Wild China

HOW FRENCH ENGINEERS HAVE CONQUERED NATURE AND LAID THE GREAT YUNNAN RAILWAY.

WHEN the French nation finally made its peace with China on June 9th, 1885, after some three years' persistent conquest in the south-east corner of the Celestial Empire, and French Indo-China came into political being through the cession of some 300,000 square miles of Chinese territory, France secured a firm foothold upon the Eastern Asian continent. But the country was regarded as being practically worthless. The fact that only some 16,500,000 people eked out a miserable existence in this vast expanse of territory undoubtedly lent colour to this prevailing opinion.

However, as the situation became understood, it was realised that France had secured a decided strategical advantage, because it was an excellent point wherefrom to tap the rich trade of Central China. Arteries of communication were required urgently, and the French decided to provide them without delay. Railway projects were adumbrated promptly. The home government fostered this enterprise. A line was planned, first from the port of

Haiphong as far as Laokay on the Indo-Chinese frontier, a distance of about 240 miles. This provided the French interests with a point of access to the fertile Yunnan province, and offered an alternative easy route between the interior and the coast. Unfortunately, however, the Yunnan province is very rugged and broken, the ranges, from 4,000 to 7,000 feet, being intersected by deep, precipitous ravines, forming the courses for rushing rivers. The only highways were rough and primitive cart tracks, so that transportation was both uncertain and costly, as well as being insecure.

The French Government thereupon advanced a project for continuing the line 300 miles up country to Yunnan-fu, the capital of the province. It was admitted to be a daring undertaking, bearing in mind the peculiar physical characteristics, yet was imperative for the success of Indo-China, and the railway already extending from the frontier to the sea.

France Finds the Money.

As a result of prolonged deliberations, China finally acquiesced in the proposal, and upon exceedingly favourable terms. The undertaking was to be completed, either by the French Government or by any private company to which the latter might feel disposed to hand over the concession. France was to find the money; the Celestial Government merely was to convey, free of all expenditure, the strip of land requisite for the right-of-way. Subsequently it was agreed that China should have the option of taking over the railway between Laokay and Yunnan-fu at the expiration of eighty years, by refunding all expenses incurred in its construction and any other details connected therewith up to the end of the term.

When the deliberations between the two Governments were adjusted satisfactorily, French financiers, in combination with constructional engineers, expressed their willingness to complete the undertaking, and to work it for the French Government, providing a sufficiently attractive financial arrangement could be completed between private and official interests. The former wanted to take over the concession lock, stock and barrel. The suggestion was received favourably, and a commission was dispatched to the East to investigate the problems on the spot, so that an estimate of the cost of the railway might be obtained.

The members of this commission did not bring back a very encouraging story. Apart from the formidable physical difficulties which would have to be overcome, and the many abstruse technical problems which would have to be solved, they laid emphasis upon the dearth of native labour, the troubles that would arise in maintaining the commissariat of the camps in the interior, and the heavy expenses that would be incurred in regard to transporting material to the grade.

Prospectors' Difficulties.

The project was threshed out thoroughly with the assistance of the information gained on the spot, the French Government estimating that the scheme could be fulfilled for £3,840,000 for some 290 miles. The concession was transferred to private interests, which were to construct and operate the railway at their own expense for a term of seventy-five years. The Government undertook to guarantee bonds at 3 per cent. on £3,640,000; the French colony of Indo-China advanced a further £500,000; while the existing line of 240 miles between Laokay and Haiphong was handed over, so as to facilitate a through working line 530 miles in length, for a similar term of seventy-five years.

Financial Arrangements.

When the financial terms were completed a hitch arose. The concessionaires did not regard the projected route of the line with favour, as it was found to introduce a ruling grade of 3·5 per cent.—185 feet per mile—with curves of only 164 feet radius, in order to overcome the difference of 3,708 feet in level between Sinkai and Mongtze,

BUILDING A BASCULE OF THE FAUX NAM-TI BRIDGE UP ONE OF THE CLIFF FACES.

a distance of about 53 miles. It was admitted that in any event the mountain section was certain to be heavy, as the range dividing the Red River and the Pataho River basins is precipitous. But the company's engineers considered that the foregoing factors were too adverse, and that an easier route might be found.

Thereupon fresh surveys were made, and at last a new route was discovered. On paper it certainly appeared to be preferable to the original location, inasmuch as on the heaviest part of the mountain section, 53 miles in length, the ruling grade was reduced to 2·5 per cent—132 feet per mile—while the curves were opened out to a minimum radius of 328 feet. Another apparent advantage, as compared with the first location, was the fact that whereas the latter introduced a maximum grade of 132 feet per mile in the Pataho River basin, on the new survey this maximum was pulled down to 1·5 per cent.—79·2 feet per mile—with minimum curvature of 328 feet radius. The chief engineer also estimated that the revised route would effect a saving of 28 miles between Laokay and Yunnan-fu. Unfortunately in this last-named feature the engineer ultimately was disappointed.

The line is of metre gauge (3 feet $3\frac{1}{3}$ inches), and the 50-pound rails are laid upon trough steel sleepers, weighing 77 pounds apiece, so that the line conforms with the general ideas of a pioneer track. The stations likewise are of this description, at present being disposed only here and there where the local conditions demand such facilities. For the first few miles out of Laokay the railway builders experienced no untoward difficulties, construction being carried forward with tolerable ease, as, the work being in close proximity to a flourishing centre, little trouble was experienced in regard to labour. But when the engineers swung into the gorge of the Nam-ti River they encountered obstructions and difficulties of every conceivable description. In fact, the going proved so hard that it threatened to wreck the whole enterprise, more particularly when it became necessary to run through a narrow gulch, carrying a turbulent affluent of the Nam-ti, and known as the Faux Nam-ti. The waterway is little else than a brook, but it babbles through a wonderful canyon, where the walls sheer up almost vertically to a height of some 1,200 feet.

The plotting of the line necessitated throwing the metals from cliff-face to cliff-face over a gap 215 feet wide, and 335

feet above the floor of the rift. It involved driving through a towering spur, so that the line was brought to the defile by means of a tunnel in the south vertical wall, and had to penetrate the opposing precipice in the same manner.

The question of bridging this chasm expeditiously and inexpensively puzzled the engineers. Ordinary bridge-building methods were quite impossible. Falsework could not be adopted owing to the height of the permanent way above the valley floor, while building upon the cantilever system would have presented some pretty problems, owing to lack of elbow room. The situation recalled that in which Meiggs found himself when he had to span the Infiernillo Gorge on the Oroya Railway in Peru, except that the bridge had to be set at a greater height in this instance.

Finally a solution was offered by M. Paul Bodin, the chief engineer to the Société de Construction des Batignolles. His suggestion for a steel bridge was certainly novel, but as none better was forthcoming it was adopted. It comprised the fashioning of two bascules, one on either side of the gorge, which were to be lowered after erection until they met and were connected in the centre. Upon this inverted V-shape structure the bridge carrying the track was to be built.

It was an ingenious idea, and, as events proved, it solved the problem very completely. The grade was driven through the cliff face on the railhead side, so that the tunnel overlooked the gulch. Men then descended the cliff face to a suitable point immediately below the bore, and prepared the foundations for the anchorages of the bascule. It was slow and dangerous work, as the precipice was steep. Considerable time was occupied in chipping away the rock, so as to permit movement between

THE BASCULES OF THE FAUX NAM-TI BRIDGE SET AND CONNECTED.
Showing the ropes whereby each section was lowered.

the tunnel and the foundations by means of ladders. Simultaneously, other toilers scaled the cliff face with ladders to a point immediately above the tunnel, where the rock face was scooped out to form a big cave. Here a windlass was rigged up, which was used for lowering the required material to the men working upon the foundations.

These preparations had to be completed on each side of the chasm, although on the north face the toilers were not cramped so severely, seeing that this precipice sheers upwards at a sharp angle, instead of vertically. Thus the men were able to contrive a platform in front of the tunnel mouth from which to pursue their tasks, whereas on the south side everything had to be conducted from the tunnel portal itself.

Primitive Transport Service.

Seeing that the railhead was some 20 miles to the rear when the bridge was commenced, the engineers were hampered very seriously by lack of transport facilities. There was only a primitive wagon road, such as is laid often in such undertakings to feed the camps ahead of the end of steel with material, men, etc., but this failed to meet the situation. Animals for transport service were difficult to obtain, so coolies had to be pressed into service as carriers. Under these circumstances the weight of the component pieces of the steelwork had to be kept down very rigorously, but it was found impossible to reduce certain sections to less than 13 hundredweight. With such weights, and advancing over broken ground, large gangs of coolies were required to handle the heaviest and bulkiest pieces of steel.

How the Bascules were Built.

Each bascule was built vertically like a tower from its anchorage up the cliff face, the steel being held in this position by cables made fast upon and passed down from the uppermost working ledge. When the steelwork of both bascules was completed, the latter reared up in front of the tunnel mouths like metallic trestles or towers. Arrangements then were completed for lowering the two sections simultaneously until they came together dead in the desired position over the gorge. The cables attached to the upper end of each tower were paid out slowly and evenly from the windlasses on each side, the riveters, sitting astride the tower ends, guiding the descent of the pieces. The actual lowering operation took four hours. When at last the ends came together and were adjusted they were connected up, and by aid of wooden plankways temporary communication was provided between the opposing cliff faces. It was a delicate and ingenious operation, which, however, was fulfilled with complete success.

The Bridge Completed.

Once the legs of steel had been set the erection of the bridge proper proceeded apace. Short steel towers were built on the humps of the bascules to support the deck. The spans of the latter were erected in the tunnel, and then launched over rollers by the aid of cables, until they came into the requisite position. From end to end the bridge measures 220 feet 4 inches at the track level; the distance between the heels of the bascules is $180\frac{1}{2}$ feet; and the rails are laid 335 feet above the bed of the river below.

While the Faux Nam-ti gorge bridge possibly constitutes the most striking piece of work upon the Yunnan Railway, the builders were sorely harassed at other points innumerable. The rock of which the mountains are composed is particularly susceptible to the ravages of the weather. The result is that it breaks up extensively, and very quickly precipitates formidable landslips and rock slides, which, owing to the generally prevailing steepness of the mountain flanks, assume destructive proportions. Time after time hill-side excavations completed in dry weather were obliterated during the following wet season. The overhanging masses of rock, slipping

bodily, crashed down with tremendous force upon the railway, and often long lengths of permanent way were wiped out of existence. These movements are to a very appreciable degree assisted by springs running in all directions, which come to life suddenly during the rainy season, as well as by thick layers of treacherous clay, forming strata in the rock, which, under the action of moisture, slips and slides in a startling manner.

THE BASCULES OF THE FAUX NAM-TI BRIDGE, CONNECTED, SHOWING TEMPORARY GANG PLANKS.
At the right may be seen the railway before it enters the cliff to reappear at the tunnel.

The cracks, crevices, and rifts in the mountain flanks also proved serious obstacles. In order to preserve the alignment and grade it was necessary to throw heavy retaining walls across these interruptions, filling the space behind with masses of rock and debris which had been brought down from higher levels by the disintegrating forces of Nature. Unless careful attention were devoted to the adequate draining of the ground behind these walls disaster was inevitable. On one occasion, where a large wall had been thrown across a hollow and filled in to grade level, the whole collapsed under the weight of a passing construction train, the engine breaking away from its couplings and pitching into the river some 50 feet below, owing to the water having undermined the foundations of the earthworks.

When the railway was commenced the engineers somewhat underestimated the force and effect of these sliding movements, and the protective walls proved too weak for their purpose. Many cracked, or were burst outwards by the weight and sliding pressure behind, with the result that they had to be demolished and rebuilt upon a heavier scale. The torrential rains also played sad havoc with the best of designs time after time. Miniature torrents poured down the gullies, searring the steep mountain slopes or soaking into the ground to

flow through cracks and crevices in the main mass of rock, effecting their escape behind the walls, where they were pent up until at last the force exerted by the accumulating water caused the walls to bulge outwards and be carried away by the suddenly released pressure. As these disturbing factors, in many instances, did not reveal themselves until some time after the work had been completed, the engineers were kept on tenterhooks. The completed portion of the line had to be watched vigilantly so as to enable repairs and re-inforcing to be carried out directly signs of weakness became manifest.

But the rock slides constituted one of the most implacable foes. A mountain spur or crag which appeared able to defy the elements for centuries would collapse suddenly, and, coming down, would smash the permanent way to fragments, or bury it completely. On one occasion over 100,000 tons of rock got loose in this manner, and having a clear helter-skelter run of several hundred feet down the steep slope, hit the line with tremendous force, carrying it away bodily and leaving a tremendous gap where solid rock had existed previously to support the metals

RIVETING UP THE TRACK DECK OF THE FAUX NAM-TI BRIDGE.

In order to save time in reconstruction, and to permit the construction trains to cross the breach, so as to keep the camps beyond the railhead adequately supplied, the engineer hurriedly constructed a light metal bridge which he rolled across the gap. It served its purpose for the time being, and stood securely while a massive structure of concrete was built beneath, the cavity being filled up completely in this manner. Even this heroic expedient did not fail to be subjected to a heavy pounding, as another landslip caught it, and knocked it about somewhat badly, but this damage was repaired speedily.

In 1906 the enterprise was brought face to face with threatened disaster. The

THE FAUX NAM-TI BRIDGE COMPLETE.

It measures 220 feet 4 inches in length, and the rails are 335 feet above the river.

interests which had undertaken the constructional operations succumbed to the long string of difficulties and troubles which beset the work.

Financial Trouble.

It was seen that the original estimates would prove completely insufficient, so a whole reconsideration of the project became necessary. The concessionaires took over the work from the railway building organisation, and approached the Government for further financial assistance. The situation was reviewed and discussed at length, the upshot being that the French Government, satisfied that the completion of the line was certain to be attended with a richly remunerative traffic, introduced a supplementary estimate of £3,280,000, bringing the expenditure to £6,620,000, to enable the work to proceed. Of this total the colony of Indo-China was held responsible for £2,060,000.

The rainfall, the insalubrity of the climate, the shortage of labour, and the difficulty in handling material owing to the absence of existing highways superior to rough cart-tracks, hit the railway builders hard.

Climate Difficulties.

From the middle of June the weather is extremely hot, and some time elapses before the European becomes acclimatised. The rainy season is equally as trying to the western worker. When the task was in full swing a vast army of 65,000 men were scattered over the grade. Many of these communities had to be housed as well as fed by the builders.

The labour troubles were endless. Emissaries had to be sent out far and wide to recruit coolies for the grade. As these were all Chinese, and worked under Chinese middlemen, some time elapsed before the French engineers became familiar with the peculiar prevailing conditions.

Chinese Labour.

The middlemen, resolved to make an excellent thing for themselves out of the transaction, sweated the labourers, thereby diverting the greater proportion of the money disbursed under wages into their own pockets. Quarrels between the coolies and their "bosses" were of repeated occurrence. Riots broke out among the men, who became dissatisfied with the small pittance they received, owing to the avariciousness of the labour contractors, and considerable damage was done from time to time to the railway property. Once or twice the disaffection assumed the proportions of well-organised insurrections, which were not quelled without extreme difficulty.

Despite these exasperating difficulties and delays the railway was carried to its inland terminus at Yunnan-fu by 1910, the 290 miles having occupied some eight years to complete.

After Eight Years.

Although the cost of construction was so inordinately heavy, the owners regard the future with placidity, as the capital of the Yunnan province is in direct quick touch with the coast. In the first year of its operation 73,000 tons were carried over the line. It is impossible yet for the road to be brought to its full carrying capacity, owing to the permanent way not having settled down sufficiently to admit of the operation of heavy fast trains.

A curious circumstance was revealed upon the completion of the enterprise. India has a rich trade with Yunnan, especially in cotton cloth and yarns. This traffic has been conducted overland from its beginning.

Conservative Prejudice.

When the railway was opened it was surmised that this overland business would cease, and constitute a source of revenue to the steel highway, reaching Yunnan via water from Indian ports to Haiphong, and thence over the new line. But the first year's working of the railway did not make the slightest impression upon the overland transportation from India. The merchants continued to dispatch their goods on the backs of animals by the circuitous difficult journey of 32 days over

dangerous trails and rugged mountain paths; and, what was a more disturbing factor, could place them in Yunnan-fu markets at a profit against the railway-borne article. Whether the line eventually will supersede this anomalous and apparently uneconomical competitive route time alone can prove, seeing that the ways of Chinese trade are notoriously difficult to fathom.

A certain hostility to the line exists among the Chinese of the interior. This attitude is somewhat explicable, since not only are the railway transport charges somewhat high, but a "transit tax" is levied upon all foreign goods, which are not of French or Indo-Chinese origin, carried between the seaboard and Yunnan-fu. In order to rid themselves of this disadvantage a group of wealthy Chinese citizens and merchants are fathering a competitive route between Yunnan-fu and the coast, lying entirely through Chinese territory. It is a daring undertaking, but now construction has commenced in grim earnest it is probable that the scheme will be completed. Rate wars then are certain to develop, but, seeing that the Chinaman is essentially patriotic, he will be certain to prefer the route through his own country, even if it be somewhat longer and occupy more time, to one extending through foreign territory, especially when there are financial considerations at stake. The merchants of Yunnan-fu itself are anticipating the opening of this line very enthusiastically. In time this new route will be to the benefit of British trade, inasmuch as it is intended to link this Chinese line with others running to Hong Kong.

The French, however, view the future with buoyant optimism, confident that in a few years the traffic will have developed to such a potential degree as to render the railway highly profitable. The only adverse forces which they fear are those of Nature, who in her playfulness may overwhelm the narrow line from time to time, thereby not only throwing traffic all sixes and sevens, but offering the engineers some costly and baffling puzzles of a technical character.

BUILDING THE FAUX NAM-TI BRIDGE.
The North Cliff face, showing three working levels.

A LOCOMOTIVE FITTED WITH DYNAMO (MARKED BY ↓) FOR HEADLIGHT.
The dynamo is turbine-driven and generates current for the headlight and three incandescent lamps in the cab.

Railway Searchlights

A DESCRIPTION OF THE POWERFUL ELECTRIC HEADLIGHTS WHICH ILLUMINE THE TRACK HALF A MILE AHEAD OF THE LOCOMOTIVE

THE public is notoriously exacting and querulous in matters pertaining to travel. It sees no reason why the same speeds should not be maintained under the blackness of the night as during the brilliancy of day, disregarding the huge strain that is thrown upon the senses of the driver. He is expected to pick up any possible obstacle on the metals a hundred yards ahead at midnight as readily as at midday. If the conditions under which the driver labours are revealed to the passenger, the latter retorts in his ignorance that the driver has his locomotive headlight to assist him to detect dangers ahead. When he is told that such a light is useless, and is rather intended for identification purposes by railway operators, such as signalmen and others, he is somewhat nonplussed.

So far as the United Kingdom is con-

cerned, the glimmering oil light may be adequate. The lines are fenced in, are well patrolled, and are protected efficiently by block signalling devices, but in new countries, where settlement is sparse, the conditions are vastly different. Often the line is not fenced, or only in a perfunctory manner, so that an eye has to be kept open for big beasts of the bush, which are apt to turn the right of way into a promenade. A bridge may have collapsed; a tree may have been blown across the metals; a boulder may have rolled down the mountain-side and have broken up the road; a wandering stream may have washed out a long length of permanent way, or have submerged it to an impassable depth. Is it surprising, therefore, that in some countries railway traffic is held up entirely 'twixt dusk and dawn?

Necessity for Headlights.

But the public must not be condemned to daylight travelling only. It has become accustomed to luxurious sleeping coaches, and has developed the tendency to move from point to point during the hours when business is suspended, and sleeps away the interval of inactivity. In order to meet these requirements attempts, therefore, were made to provide the driver with a more efficient means of illuminating the track ahead for a considerable distance, so that perfect safety might be attained when travelling at express speed during the night.

Woolley's Experiments.

The electric light was an obvious handmaid to this end. Accordingly, efforts were made to adapt it to railway service. Experiments were undertaken in this country, but the lack of encouragement for such a contrivance was a deterrent to endeavour. Besides, so many difficulties of an exasperating nature loomed up and defied subjugation so completely that inventors became somewhat disheartened, and abandoned their labours. In the United States, however, where the demand for such a searchlight was more acute, inventive effort was not cast down so easily. One, if not the first, experimenter was Leonidas Woolley. He commenced his experiments at his home in Dayton, Ohio, and laboured long and hard at the perfection of a small, compact, and simple device. Before he had carried the idea sufficiently far to build a working model, he moved to Indianapolis, Indiana. Here he produced a small electric headlight machine in 1883, and success seemed assured. But there came a bitter disillusion. The device was rigged up on a locomotive, and burned promisingly while the engine was standing still. Directly it commenced to move, however, the light went out, and resolutely refused to burn while the locomotive was in motion. Woolley dismantled his apparatus, and, somewhat chagrined, took it back to his home for further development upon different lines.

Jenney's Attempt.

His initial effort spurred another inventor to action. This was Charles J. Jenney, who, in 1885, produced an electric headlight which was placed on one of the engines of the Big Four Railroad, running between Indianapolis and Cincinnati. But Jenney experienced difficulties similar to those which had befallen Woolley, although the railway company in this instance, recognising the possible germ of a great idea, persevered with the innovation, and endeavoured to make it work. Still, their perseverance proved unavailing, and so, after making a few trips, the machine was taken off.

An Unreliable Light.

Woolley had by no means been idle, though it was not until 1887 that his next effort attracted attention. In that year a new equipment was brought out by the American Headlight Company, and was placed upon an engine of the Cleveland, Akron, and Columbus Railroad, and also on one of the Pan Handle Railroad, running between Indianapolis and Columbus,

RENDERING RAILWAY TRAVEL

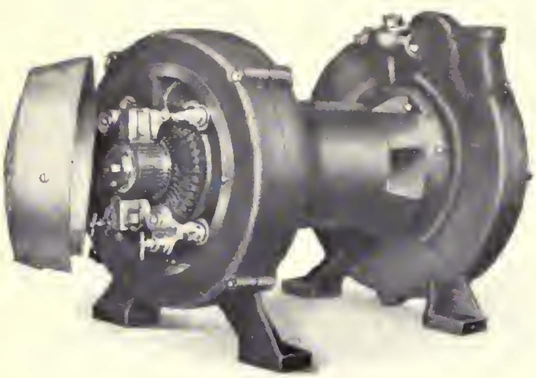
The electric searchlight of the locomotive when focused correctly, as in this illustration, throws a magnificen
a mile ahead. This striking picture, photographed by the electri

Photograph by courteous permission of the Pyle-National Electric Headlight Company, Chicago, U.S.A.

AT NIGHT AS SAFE AS BY DAY.

white ray sufficiently powerful to enable the driver to detect an object the size of a man on the road half headlight itself, shows how brilliantly the track is illumined.

Ohio. While these machines were considered to be a marked improvement upon anything which had been attempted in regard to electric locomotive headlights up to this time, they proved far from reliable. The railways struggled with them for several weeks, and then reluctantly relinquished them ; the manufacturing company discontinued experiments and went out of business.



THE TURBINE DYNAMO OF THE PYLE-NATIONAL ELECTRIC HEADLIGHT.

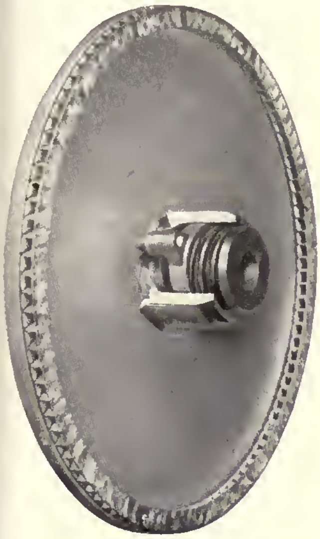
In 1888, Robert B. F. Pierce, of Indianapolis, appeared upon the scene. He foresaw the future of such a headlight, and determined to bring it to a successful issue. He interested a few of his associates in the project, among whom was George B. Pyle, an electrical engineer. The patents of other inventors were acquired, and with this nucleus the National Electric Headlight Company was organised, with Pyle toiling strenuously to evolve success out of failures. Finally, he effected certain improvements, and a machine was submitted to the railways. It was fitted to an engine, and after a few galling failures and many adjustments, completed a journey from one terminal to another without a breakdown. This achievement was hailed with unfeigned delight, and the distinction of being the first company to produce a working electric headlight thus belongs to the above organisation. But the machine did not triumph completely. It proved quite a trouble-maker as time went on, and the railways only embraced it with lukewarm enthusiasm. The movement languished, the company experienced many vicissitudes, and terminated its existence upon the death of Mr. Pierce.

In 1897, Mr. Royal C. Vilas took up the idea, and founded the Pyle-National Electric Headlight Company. He encouraged further experimenting, although up to the time of his taking up the subject fewer than 175 electric headlights had been sold in the country. Under this powerful stimulation, the invention was improved out of recognition within a very short time. At last Vilas announced that he had got just what the railways required, and they were given the headlights to test, and to satisfy themselves.

The optimism of the inventors proved to be justified fully, and appreciation of the invention was forthcoming instantly. In the following year 472 of these headlights were installed upon the locomotives of the various railways throughout the United States and Canada. To-day its powerful penetrating beams are seen illumining the pathway through the towns, over the plains, and through the gloomy fastnesses of the mountains from the Straits of Magellan to Alaska ; in the antipodes, China and Japan, India, Russia, and Scandinavia.

The success of this invention, once its reliability was assured, has been phenomenal. This is due to the efficiency of the machine under all and varying conditions of railway working, simplicity of the details and construction, durability, and fool-proofness. Obviously, such an accessory to the locomotive must be unassailably reliable, free from liability to fail at a critical moment, and demand the minimum of attention on the part of the driver, who cannot be expected to be possessed of more than the rudiments of electrical knowledge.

The Pyle headlight is a small, compact machine, comprising a turbine-driven dynamo, which is mounted on top of the boiler, just in front of the cab, with suitable steam connection to the turbine, and an exhaust so arranged as to enable the spent steam to pass over the roof of the cab. A simple control is placed at a convenient point on the footplate, giving the driver complete command over the machine.



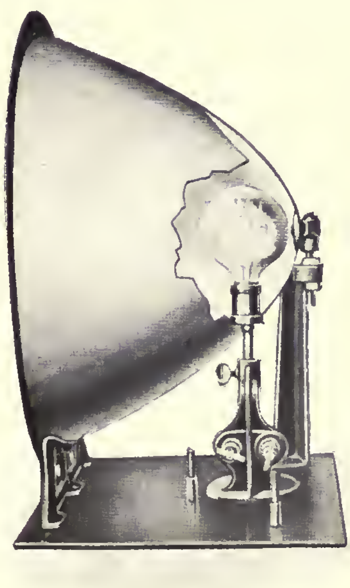
THE TURBINE WHEEL OF THE DYNAMO.

The dynamo is of simple construction, the armature being held on the turbine-shaft by one screw. The electrical balance is so perfect that no sparks are seen at the brushes when the adjustments have been made perfectly. The turbine rotor, or wheel, is of the built-up type, made from cast steel, and carrying a single row of buckets, securely dovetailed in the periphery of the wheel. The advantage of this arrangement is that all possibility of the buckets working loose, or being thrown out by centrifugal force, is obviated completely.

The governing arrangement, likewise, is of the simplest form, having but one wearing surface, the friction of which is taken up by a composition disc, so that no internal lubrication is required. The governor is set at 2,400 revolutions per minute, the normal velocity of the turbine, but the speed may be varied as desired by altering the tension of the spring through the movement of two nuts. The steam-valve and stem are made from tobin bronze, which reduces the wear and cutting effect to the minimum.

The steam is led to the veins on the rotor through a single nozzle, and attached to the nozzle-block are two guide passages, which direct the impingement and flow of the steam to and from the veins on the rotor, thereby producing the very highest efficiency that has been attained so far in a turbine of this size. The turbine-wheel is carried upon a plain sleeve bronze bearing, while the armature is mounted upon ball bearings. The dynamo is enclosed, and of the internal magnetised type proportioned to carry heavy overload without injury to the machine.

For ordinary service an arc lamp is used, and the ordinary oil headlight can be adapted to electric operation. The American locomotive headlights are more formidable than those employed in these islands. Conversion from one to the other is simple, and may be effected easily and



A HEADLIGHT WITH INCANDESCENT ELECTRIC LAMP FOR SHUNTING LOCOMOTIVES.

quickly. All that is necessary is to remove the oil reservoir and burner, together with all supports and guides from the parabolic reflector with which the oil light is fitted.

THREADING THE GRAND CANYON OF THE FRASER.

The plotting of the Canadian Pacific Railway through the mountains of British Columbia constitutes one of the greatest achievements of the railway engineer.

THE BRIDGE OVER FRASER CANYON.

The Canadian Pacific Railway—II

THE ROAD THROUGH THE MOUNTAINS

FROM Winnipeg westwards the route proposed by Sir Sandford Fleming was abandoned in favour of one nearer the International boundary. This decision was made for climatic, strategical, and financial reasons. Although the Fleming location traversed the richest stretches of the west, the company opined that it ventured into a country which was too cold to facilitate rapid development, a fallacy which was not exploded for thirty years. Again, it was considered that if the line were placed close to the International boundary it would be impossible for it to be paralleled by a Canadian rival farther south, and thus be in danger of having its traffic filched away by a competitive route. Thirdly, there was the question of expense. The Yellowhead Pass was undeniably the easiest passage through the mountains, but it entailed a sweeping detour, as compared with a more direct traverse of the range, while also heavy and expensive bridging over the wide rivers would be

entailed. As money was tight, every mile saved was a vital consideration. Accordingly the fiftieth parallel was hugged as closely as possible as far as Calgary, traversing a rich wheat country for 400 miles, and a grazing belt for 200 miles.

Across the Prairie.

The prairie is considered generally to be a level plain, but this is scarcely a correct appreciation of its characteristics. Rather is it a series of steppes, or very wide benches, mounting higher and higher from Winnipeg to the foothills of the Rockies. The country being analogous to that traversed by the Northern Pacific, the terrors of winter were kept in mind. The Arctic blizzards have a magnificent sweep for hundreds of miles without courting an obstacle, and it was feared that the railway cuttings would be subject to severe attack. Consequently the permanent way was carried on embankments as much as possible, and where cuttings were unavoidable they were given wide, flattened slopes, so as not to offer such a ready catch-pit for the drifting snow as a deep trench with steep sides. The spoil removed from these cuttings was carried some distance away and deposited in the form of a ridge running parallel to the track to form a snow screen. Subsequently wooden fencing was used for screens, these being withdrawn and stacked during the summer and set up on the approach of winter. But the snow fiend did not prove so terrible as had been feared, inasmuch as the line when first opened did not suffer a block exceeding some six hours or so at a time.

Although the contract for the railway was let to one firm, actual construction was completed by sub-contractors. The line was divided up into "stations"—100 feet sections representing the length of a chain—one or more of which were taken over by each sub-contractor. In this way construction was spread over a distance of 100 to 200 miles. On the prairie the work was easy for the most part. In summer ever ounce of muscle was crowded on and ever moment of time was pressed into servic At first the vaunted severity of the winte scared many of the graders away to mor southern climes in the late autumn, but thos who had the temerity to stay behind foun that, providing care was exercised, no il effects were suffered. Thick woollen under clothing and heavy outer garments secure the body against the cold. Fur caps wit the flaps let down over the ears protecte the vulnerable parts of the head. Heav woollen stockings encased with stout, higl leather boots, and with another pair or tw of stockings over the latter, kept the fee warm, and gave a grip upon the slipper frozen surface, while thick gauntlets hel the hands proof against frost-bite. Th cold certainly was intense, as it must b when the mercury drops some 30 or 4 degrees below, but the air was dry an crisp. The blizzard was the foe mos dreaded, but the men took the precautio to keep fairly close to their camps unde such conditions.

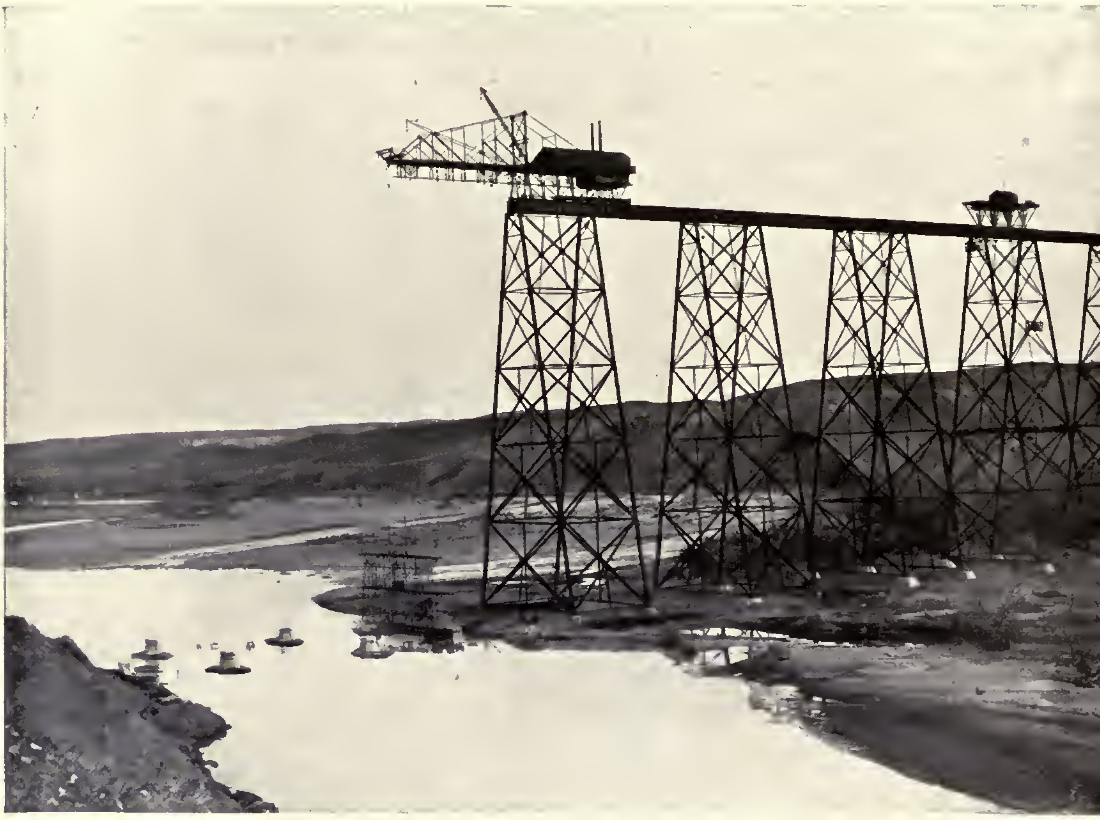
Through th Mountains.

When the company decided to follo the international boundary as closely a possible, the Government stipulated that the mountains should be crossed at least 100 miles north of the frontier, and at th same time restricted the maximum grad to 116 feet per mile. Accordingly th company decided to strike through th sea of mountains from Calgary, followin the natural troughs as much as possible The surveys proved that the end could b met most satisfactorily and cheaply b following the Bow River. This gave grade of 1 per cent.—52·8 feet per mile— the mountains being entered through natural gateway known as "The Gap." I is a tedious upward climb, winding amon the crags and crawling along terraces to th summit at Stephen, where the metals notcl 5,329 feet, the line climbing 1,901 feet i the 123 miles from Calgary.

This is the "Divide," whence the waters from the glaciers split to run down either side of the mountain on their way to the Arctic or to the Pacific. In reality it is a engineers found heavy tunnelling unavoidable. This meant the expenditure of money, which was scarce, and the consumption of time, which was more valuable, so the

THE CISCO CANTILEVER BRIDGE, SPANNING THE FRASER RIVER.

vast marsh, so that the summit was overcome without a tunnel or even a snowshed. From this point the descent is made along that wild, turbulent waterway which sprawls from one side of the ravine to the other—the Kicking Horse River. Here the descent was found to be so sudden, that, in order to preserve the maximum gradient, the engineers were enjoined to discover and run a "temporary line." They did so, but it involved the introduction of 4·4 miles with a grade of 4·5 per cent.—237·6 feet per mile—against eastbound traffic between Hector at an altitude of 5,207 feet, and Field at 4,064 feet. Moreover, a "temporary curve" of 23 degrees—249·13



BUILDING THE LETHBRIDGE VIADUCT.
Showing erecting cage just commencing work on the span over Belly River.

feet radius—had to be laid down because a short tunnel, which was accepted to maintain the alignment, collapsed suddenly from the movement of the clay through which it was being driven. This "temporary line" fulfilled all the requirements of the Canadian Pacific Railway for over a quarter of a century. It was not until the threatened competition of the Grand Trunk Pacific arose that this "Big Hill," as it was colloquially called, was abolished, as I have described in a previous chapter.

Issuing from the Rockies at Golden, on the banks of the Columbia River, another frowning barrier looms directly ahead—the Selkirks. It was impossible to follow the waterway, as it runs for many miles to the north to describe a curve around the extremity of the mountainous barrier, so the engineers went straight ahead. The going through the Rockies had been exasperating, but that through the Selkirk was a thousand times more so. Here th railway engineers had no trail of the India or the *coureurs du bois* of the Hudson Ba Company to help them. They were com pelled to seek a path for themselves, a very few, if any, Red Men ever had pene trated the Selkirks, the twisting, circuitou Columbia River being their highway.

An American engineer, Major Rogers, i conjunction with Mr. Moberly, set out t discover a possible highway through thi chain, and it proved an exciting an adventurous undertaking. Eight Indian accompanied the first-named, four of whor were lost at one stroke. While crawlin round a dangerous lofty ledge they slippe over the side and were seen no more But the intrepid engineer succeeded, an the route followed by the Canadian Pacifi Railway through this range offers an inter

esting, and one of the very few instances where the White Man's trail has preceded, instead of following, that of the Indian.

There was one fact which Major Rogers impressed upon his colleagues on his return. The engineering difficulties were not particularly forbidding, but there was one far more formidable antagonist—snow. The steep slopes of the mountain forming this barrier lend themselves to avalanches and rock slides, and of such an awful severity as to promise short shrift for the handiwork of man. The difficulty would not be so much in laying the track as in preserving it once it had been built.

The constructional forces were concentrated upon this range, and were urged to spare no effort to accomplish as much of the grade as was possible during the short summer. The navvies responded to the call, and the permanent way grew with marvellous rapidity. True it was a pioneer line, lightly built, as the problem was to get through with all speed; but it was quite equal to the Union Pacific original track, which had been taken as a standard. When winter came round, work was suspended, but corps of engineers were left buried in the range to observe the extent, character, and paths of the snow movements, so as to enable adequate steps to be taken to protect the line. These men, virtually imprisoned in a white, frigid tomb, carried out their work to excellent effect, although their reports were rather dismaying. Their observations proved that the line would have to be protected virtually for the whole of its length across the range. Four miles of heavy timber snowsheds accordingly were built, not in one continuous length, but in 53 sections. Fortunately, there was plenty of timber in

THE LETHBRIDGE VIADUCT, ALBERTA: IT IS 5,327 FEET 7½ INCHES LONG AND 314 FEET HIGH.

the immediate vicinity, but even then the felling of the trees and the fashioning of the huge balks occupied considerable time, and construction entailed an expense ranging from £3 to £40 per lineal foot, with the price for the most part nearer the latter than the former figure.

down the sides of the crib, and, its cours being deflected, it rumbles over the roof of the sheds on either hand to expend it destructive forces harmlessly in the valle below. When this "split-fence" was trie it was found to meet the situation so com pletely that it has been adopted freely.

LOOKING ALONG THE DECK OF LETHBRIDGE VIADUCT.
Showing girders rising above the rails and forming a trough for traffic.

Yet this did not meet the situation completely. The snow, after its usual paths had been discovered and guarded, swerved with characteristic capriciousness to strike the line between the different sheds.

Sir William Van Horne, as in many other instances, came to the rescue, and solved the difficulty. He could not anticipate the path of the moving snow, but he could wreck its progress. He devised what is now known as the "split-fence." This is a massive structure of V-shape, set high up on the mountain side above the space between the snowsheds, with the apex pointing crest upwards. This fence is a heavy crib filled with boulders, while its sides are splayed. The descending snow-slide, hitting the point of the fence, is divided in twain. Each moiety rushes

Crossing the summit of the Selkirks a 4,351 feet, the engineers were faced wit another sudden descent into the Illecillewae Valley, which they overcame by a loo winding down the mountain side. It is spectacular piece of work worthy of rankin with the abandoned "Big Hill." In th course of seven miles the line swings dow 637 feet. The line strikes across a valley touching the base of Rock Peak, bend back for about a mile, gives a sharp sweep and once more cuts across the rift t pick up the floor of the valley. In th descent the line describes a double "S," and two gleaming ribbons of steel withi 100 feet of one another are seen on th steep slope.

While the builders were pushing thei metals westwards another force was grap pling with difficulties innumerable in th

eastern advance from Vancouver. The Cascades press hardly upon the Pacific seaboard in Canada, so that heavy going was encountered directly the ocean was left. The engineers followed the only practicable passage—that of the Fraser River—and they clung to it tenaciously, blasting a narrow terrace through the awe-inspiring, wedge-shaped canyons, high above the foaming torrent, to receive the rails. Progress was slow, since the cramped quarters did not permit the concentration of large bodies upon the work. Where the Fraser and the Thompson Rivers meet in swirling, scurrying madness, a heavy cantilever bridge was thrown from ledge to ledge, which ranked for many years as one of the largest in America.

Chinese as Navvies.

Labour was a constant anxiety upon this mountain section. White men then, as now, could not be obtained, except at prodigious expense. So the Chinaman was called in, even as had been the case with the Union Pacific. Three shillings a day was his pay, and the grade in British Columbia recalled the roaring times of railway building farther south. The Chinaman is a born and ardent gambler; so no camp was complete without its saloon. A certain degree of lawlessness prevailed and defied to be quelled: it was every man for himself, with life held cheaply, and pleasures of a strenuous character.

But the Chinaman, when he settles down to work, is a plodding labourer. The "Chinks" drove the steel highway through 351 miles of the roughest country in the west, where Nature was dead set against the engineer and did not give him the slightest foothold. It was blast, cut, fill, bridge, and viaduct for every mile of the way, with explosives as the only useful weapons, the roars of which punctuated the interminable chanting of the drills. But on the morning of November 7th, 1885, the roar and clanging ceased. The advancing arm from the Atlantic met that coming from the Pacific: the last spike was driven home by Lord Strathcona; Vancouver was in railway touch with Montreal. By strenuous work, Father Time had been beaten by six years, because the Government contract called for completion in 1891.

The Lethbridge Viaduct.

Since the first steel trail of the Canadian Pacific Railway was driven across the continent, an alternative route through the mountains has been taken in hand, and is advancing rapidly towards completion. This runs via the Crow's Nest Pass, some miles nearer the international frontier, through a rich coal region, and crosses the Rockies at a lower elevation. On this section, however, is a notable piece of work equal in magnitude to the re-alignment of the railway through the Kicking Horse Pass. In running the metals 38½ miles from Lethbridge to MacLeod the deep, wide ravine through which the Belly River winds had to be crossed. When these two points were linked in the first instance, the line was a pioneer road in the true sense of the word, abounding with curves running up to 7 degrees—818·5 feet radius—and with grades of 1 per cent. (52·8 feet per mile), while twenty wooden bridges, aggregating 12,063 feet, and varying in height from 9 to 117 feet, carried the metals across the heavy undulations.

As the life of the timber trestles had expired, it was decided to rebuild these 38½ miles. Instead of having so many bridges, ranging from 16 to 2,933 feet in length, to cross the depressions, the engineer consolidated them into two big structures, so as to reduce the grade, ease the curves, and decrease the mileage. The bridges constitute the most striking features of this re-alignment, the Lethbridge Viaduct, as it is called, being 5,327 feet 7½ inches in length, and with the rails 314 feet above the bed of the river at one point. The second structure crosses Old Man River,

and is 1,900 feet long, by 146 feet high in the centre.

The longer bridge is borne upon 33 lattice steel towers or bents, anchored to concrete plinths carried down to a firm foundation in the silt. The steel was set by means of a traveller which weighed 712,000 pounds in working condition. As the wind howls through this depression with great force, extreme precautions were taken to protect the men on their lofty perches, an assembling cage being supported from the end of the traveller wherein they performed their appointed task of riveting up. In this manner loss of life was minimised, only two men being killed, but not in direct connection with the work. The bridge was completed in a remarkably short space of time, notwithstanding complete cessation during the winter, owing to the extreme cold, and a strike among th workmen. In its construction 12,200 ton of steel were used, which demanded 64 cars to carry it to the site, and when th steel was set over 7,600 gallons of pain were required to give it two coats.

HOW THE C.P.R. MAKES ITS WAY THROUGH THE FRASER CANYON.
Four tunnels are to be seen in this view.

When the railway was opened for throug traffic on May 26th, 1887, many critic maintained that the railway would neve pay its way. The present prosperity o the enterprise, which now ranks as th largest individual transportation concer in the world, operating some 11,000 mile of line, has refuted the detractors com pletely. The Canadian taxpayer, howeve learned one lesson. He made a present through the Government, of £14,000,000 made up of £5,000,000 original subsidy 713 miles of completed line which cos £7,000,000, and a further £2,000,000 i

THE "JAWS OF DEATH" BRIDGE IN THE THOMPSON RIVER CANYON.

the re-purchase of 7,000,000 acres of land at six shillings per acre which had been given to the company in the first instance. At the opening date 18,000,000 acres of choice land remained from the original gift of 25,000,000 acres. The land grant in the case of the Canadian Pacific Railway, as in many other similar undertakings, has constituted its sheet anchor. It is not surprising that the Canadian taxpayer of to-day concludes that his Government made a poor bargain on his behalf, and does not view other railway undertakings with a similar liberality.

Photograph by W. Notman & Son, Montreal.

THE SUMMER AND WINTER LINES OF THE CANADIAN PACIFIC RAILWAY THROUGH THE SELKIRKS.

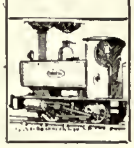
The open line is used during the former and the protected metals during the latter season.

Photograph by A. G. Wehrli, Kilchberg, Zurich.

TRAIN CROSSING THE SCHNURTOBEL BRIDGE, THE LONGEST ON THE LINE.

The First European Rack Mountain Railway

THE CURIOUS LINE WHICH RUNS FROM VITZNAU, UP THE RIGI, TO KULM, 5,905 FEET ABOVE SEA LEVEL



WHEN the possibility of moving wheeled vehicles along a pair of rails by the aid of the steam engine first was discussed it was considered quite impracticable for sufficient friction to be produced between the wheel and the rail to propel the locomotive and the train. Bearing in mind the small area of contact between the two surfaces, this feeling, in the days when the locomotive was young, is quite excusable. It was held to be imperative that the locomotive wheels should be provided with teeth or studs disposed around the peripheries of the wheels and engaging with holes in the track to secure locomotion.

Accordingly, when John Blenkinsop laid down a railway at the Middleton Collieries, near Leeds, in 1811, he introduced a rail carrying corrugated teeth, outside one of the track rails, with which a driving wheel,

mounted outside the carrying wheel, geared. Two years later Blackett, at the Wylam Collieries, argued that Blenkinsop was wrong in his contentions, and that a train could be impelled under adhesion alone providing the grade was not too steep. He proved his theories in a practical manner, with the result that the Blenkinsop tooth system became superseded, and Stephenson, when he directed his energies towards the perfection of the steam locomotive, adopted the adhesive principle.

Although Blenkinsop was proved to be wrong in one phase of the argument, he unwittingly offered the railway engineer a means of overcoming gradients which are too steep to be worked under adhesion. He conceived the rack railway, which now enables the masses to indulge in the sport of mountaineering in safety, luxury, and comfort. Blenkinsop's rack railway was torn up—sections are preserved in the South Kensington Museum—but the principle did not lie dormant for many years. An American engineer suggested that the method should be adopted on steep grades, the rack being laid between and not outside the metals. In 1847 a railway between

THE FIRST TYPE OF LOCOMOTIVE, WITH VERTICAL BOILER, USED ON THE RIGI RAILWAY.

Indianapolis and Madison was built upon this principle. In 1858 another American, Sylvester Marsh, concluded that, although the rack might be superfluous in connection with trunk line working, it could be turned to useful purpose for scaling lofty mountains merely for the transportation of sightseers and tourists. He sought and obtained the concession to build such a line to the top of Mount Washington, in New Hampshire, U.S.A., and in 1868–9 this line was built.

But although Marsh indicated the possibilities of the rack railway, it was Switzerland which brought the idea to an advanced and perfected stage of development. This was only to be expected, seeing that the "playground of Europe" is vitally dependent upon its tourist traffic. Obviously,

the more attractions it can offer to visitors the heavier must be its revenue from this source. Tourists will travel miles to enjoy a "magnificent panorama," and what better coign of vantage is possible than a mountain top whence are unfolded rolling vistas of glacier, lake, river, and snow-crowned peak? To the Swiss nation the invention of the rack railway has been the biggest boon of the century; "Mountaineering by rail" has become the most popular pastime in the world.

Still, in Switzerland, this movement was born independently of America. While Sylvester Marsh was striving to secure his concession for the Mount Washington railway, Mr. Nicholas Riggenbach, who took the first steam locomotive into Switzerland in 1847, and who was locomotive superintendent of the Central Swiss Railway in Olten, took out a patent on August 12th, 1863, for a new system of track and locomotives for the ascent of mountains—a rack railway and locomotive for operating the same. Nothing further appears to have been done in connection with the idea by the inventor, who at this time apparently was ignorant of Marsh's similar efforts in the United States. But when the Mount Washington railway was completed Riggenbach made a trip to North America, and inspected the line, which, though independently conceived, was virtually built upon the principle he had evolved and had patented seven years previously. Upon his return to his native land, in 1869, he immediately built a short length of railway working upon the rack system at some quarries near Berne, where he tested his theories.

When this railway was completed naturally it became an object of interest among engineers. Among these were Messrs. Naeff and Zschokke. They were impressed with the possibilities of the idea, and, joining forces with Riggenbach, it was

THE LATEST TYPE OF LOCOMOTIVE IN USE ON THE RIGI RAILWAY.

decided to test it upon a comprehensive scale—to provide some popular mountain with this means of ascent. Casting around, their selection fell upon the Rigi, which had come into popular favour because Heinrich Keller, the well-known geographer, had returned from a trip to its then difficult summit, with enthusiastic descriptions of the wonderful views revealed from its crest. His pictures so appealed to the public, and made such a deep impression, that kindred spirits, Dr. Abel, Mr. Escher Von der Luith, Dr. Horner and Mr. Keller, subscribed between them the sum of £100 for the provision of a hotel upon the Rigi summit, for the convenience of those who toiled to the top to enjoy the view. It was an unpretentious building, being merely an Alpine hut such as is to be found on every hand throughout the Swiss and Austrian ranges to-day for the convenience of mountaineers. It was appreciated by the scores who, attracted to the crest, embarked upon the journey, and was the forerunner of the existing magnificent hostelry which now crowns the summit of the Rigi.

The Route of the Line.

Thereupon Riggenbach, Naeff, and Zschokke sought a concession to provide the Rigi with a mountain railway, since it was realised that this peak offered the most promising opportunity to sound the public attitude towards such facilities. The requisite powers were obtained, and Vitznau, at the foot of the mountain, on the shores of Lake Lucerne, was selected as the lower terminal. From that point the line follows a winding ascent to Kulm, at an altitude of 5,900 feet, the total length of the line, which is of standard gauge, being 4·38 miles. The maximum gradient was set down at 20 per cent.—1 in 5—while the curves are of 591 feet radius. The configuration of the mountain side fortunately assisted the constructional engineers, the only two heavy works being the Schwanden Tunnel, 240 feet in length, and the immediately adjacent Schnurtobel Bridge, 235 feet long, supported on five trestles, over the Schnurtobel gorge, through which rushes the Grubisbach 70 feet below. Both the tunnel and the bridge are upon the maximum grade, while the bridge is on a curve of 591 feet radius.

Riggenbach's Rack Rail.

The rack rail designed by Riggenbach differed from that used by Marsh on the Mount Washington railway, and was a distinct improvement thereon. It was placed centrally between the running rails, and was formed of two channel irons $4\frac{3}{4}$ inches deep by $2\frac{3}{8}$ inches wide, the vertical web being $\frac{1}{2}$ inch, and the flanges $\frac{2}{5}$ inch thick. These two channel irons are spaced 5 inches apart, and the teeth of wrought iron are riveted into them at each end. Instead of using round teeth, as Marsh adopted, Riggenbach preferred the taper form which experience has shown to be preferable, inasmuch as it not only ensures safe locking of the gear at different depths, but resists more efficiently the tendency of the gear-wheel to climb the rack, so that full security against derailment is ensured. Riggenbach's type of tooth, with certain modifications, has been adopted since in all types of racks for railways. When built the iron track was laid upon longitudinal and transverse sleepers, but the effluxion of time demanding the overhauling of the railway in 1885, the wooden sleepers were removed in favour of iron, while the track was relaid with steel rails.

A Vertical Boiler Locomotive.

The first locomotive, like the rack, had to be designed especially for the work, and was of unusual design. It was constructed at the Olten works of the Central Railway, with which Riggenbach was associated, and comprised a vertical boiler, set at such a rake to the horizontal as to reduce as far as possible the variations in water level arising from the differences in the gradients which had to be negotiated. The boiler was mounted on a four-wheeled carriage,

THE TRAIN CLIMBING THE RIGI IN WINTER.

Photograph by E. Goetz, Lucerne.

VITZNAU, THE LOWER TERMINUS, SHOWING TURNTABLE AND SIDING TRACKS.

in the event of an accident t the driving rack wheel.

The carriage—one comprise each train then as now—wa pushed up the mountain an trailed in the descent, but wa not coupled to the engine. I had seating capacity for 5 passengers, and was fitted wit powerful independent brake so that even when fully loade it was able to be pulled u instantly on the steepest bank independently of the engin in case of a mishap befallin the latter. The normal brakin facilities on the engine operate upon the disks of the crank shaft. In the descent no stean was employed, movement bein by gravity controlled by an in genious method of introducin air into the steam cylinders the valves of which wer reversed while the regulato was shut off. Air, drawn int the cylinders by the movemen of the pistons, became com pressed, thereby exerting gentle retarding effect upor

the rear axle with its wheels running loose. The cylinders were placed outside the frames, and by means of connecting rods and cranks drove the intermediate shaft, which carried two pinions gearing into spur wheels having 43 teeth and keyed on the driving or lower axle. On this axle also was keyed centrally the toothed wheel, 25 inches in diameter, and having 20 teeth, which meshed with the teeth in the central rack. Consequently, through this gearing, the vehicle was propelled either forwards or backwards. The second, or upper, axle not only carried the two carrying wheels running along the rails, but a central spur wheel as well, which geared with the rack. This wheel was practically an emergency braking device to be brought into action

the progress of the train. A valve worked by the driver and throttling th exhaust of the air, served to govern thi braking action.

After some eleven years' service th vertical boiler was abandoned in favou of the horizontal type. Similar considera tions concerning changing levels of th water arising from the differences in th gradients had to be borne in mind, and thi gives the engine the appearance of tilting forward when on a level track. In th latest Rigi locomotives the cylinders ar placed at the leading end, outside th frames, the driving cog-wheel, engaging with the teeth of the rack, owing to it larger diameter, being placed close behind the front carrying axle. The rear axl

carries an emergency rack brake as in the original engine, while the disposition of the brakes is the same, with the addition of a centrifugal governor whereby the speed is controlled automatically. When this limit is exceeded the steam brake is brought into service. This automatic steam brake is a special and ingenious device, and its reliability and efficiency having become emphasised, the Government now compel its installation upon all steam rack railway locomotives used upon the Swiss lines.

Travelling upon the Rigi railway cannot be said to be excessively fast, seeing that it averages about 4·7 miles per hour with an average load of 25 to 28 tons. Therefore any qualms on the part of the timorous are unnecessary. To overcome the 3,937 feet difference in altitude between Vitznau and Kulm 74 minutes are occupied in either direction. This may seem slow; but before the coming of the railway the climb involved a tedious, fatiguing toil afoot of $3\frac{1}{2}$ hours.

The railway was completed in 1871 and proved an instant success. The novelty of mountaineering by rail proved irresistible, and the novelty never has worn off so far as the Rigi is concerned. Now more than 120,000 passengers are carried up and down in the course of the year. The ascent costs about 5s. 10d.; the descent 50 per cent. less. In summer ten trains are run daily in each direction, and if the exigencies so demand the total may be raised to eighteen, enabling some 600 passengers to be sent to and fro in the day.

The Rigi railway, being the first of its character in Europe, always has compelled historic interest, but since the first train crawled to the summit of the mountain in 1871 mountain peaks innumerable have been subjugated by the rack railway, operated both by steam and electricity.

ROMITI STATION, WHERE THE ASCENDING AND DESCENDING TRAINS PASS

Photograph by permission of the Great Eastern Railway.

THE GREAT EASTERN "DECAPOD" IN COMPARISON WITH AN ORDINARY TANK ENGINE.

Locomotive Giants—II

SOME ENGLISH DEVELOPMENTS IN MONSTER ENGINES

IN discussing the big locomotive, as it is exemplified in various parts of the world, especially in North America, there is a tendency to overlook what has been, and still is being, accomplished in Great Britain. While the railways of these islands offer nothing to compare in size and power with the Mikado, Mastodon, and ten-wheel Consolidation, or the articulated Mallet, yet they have produced many engines which compel attention.

So far as the British Islands are concerned the physical characteristics of the country render the mammoth engine unnecessary. The engineers who laid our steel highways in the first place recognised the significance of the easy level line. Nature certainly favoured them in their work, inasmuch as there are no towering mountain chains to overcome, necessitating sudden heavy rises and falls. The summit level of 1,484 feet above the sea, attained on the Highland Railway between Dalwhinnie and Dalnaspidal stations, whic represents the highest point at which th shriek of an express is heard in Grea Britain, appears a mere molehill beside th 10,836 feet notched in the Marshall Pas of the Denver and Rio Grande, or th 5,329 feet attained upon the Canadia Pacific among the Rockies.

Nor are the gradients so severe. Wherea a train may be called upon to pant an throb for mile after mile up a bank risin 1 in 25 through the Rockies and Sierras climbs of 1 in 50 represent the averag maximum upon British railways, and i the majority of cases these are over onl short distances. True, here and ther are short stretches of steeper banks. Fo instance, on the South Eastern and Chatham Railway there is a heavy 594 yards ru between Canterbury and Whitstable wher the engine has to toil up a rise of 1 in 28 Again, on the North Eastern Railway ther is a very wicked piece of road betwee Kirkby Stephen and Barnard Castle, wher the train is called upon to overcome

difference in level of 725 feet in 8·75 miles, while between Ferryhill and Hartlepool is the Kelloe Bank, which offers an incline of 1 in 36 for about 1,300 yards. The London and North Western Railway also has one or two crippling rises at 1 in 33 for short distances upon its system, and on the Great Northern there is a heavy three miles between Drighlington and Batley West, where the ascent ranges from 1 in 40 to 1 in 50. In many instances, however, these adverse stretches exist only on branch lines, the main through roads, over which the fastest and heaviest traffic moves, having been built or improved to offer a ruling gradient which is by no means hard upon locomotive effort.

The ruling gradient, it may be pointed out, constitutes the key to the whole situation. As its name implies, its severity rules the hauling and speed capacity of a single engine. For instance, suppose a stretch of road 100 miles in length has a maximum rise of 1 in 200, and that a single engine is able to move a train weighing 500 tons over this section at 30 miles an hour, but on the succeeding stretch the maximum grade becomes 1 in 100. Now, the foregoing engine will be unable to continue handling the same load at the same speed. The train either will have to be divided, a more powerful engine used to negotiate the 1 in 100 banks, or additional locomotive power will have to be utilised, either in the capacity of a pusher or a pilot.

In these islands possibly the issue is not so serious as in other countries where the physical conditions vary from wide expanses of gently rolling plains to towering mountain ranges. But in order to minimise the difficulty the engineer strives to "bunch" his grades. The line, say, of 1,000 miles is split into sections or divisions, each of which indicates the extent of one engine's run with the train. If the engineer

Photograph by permission of the Great Eastern Railway.

THE "DECAPOD": IT HAD FIVE PAIRS OF DRIVING WHEELS AND WEIGHED 70 TONS.

THE GREAT WESTERN LOCOM

Over-all length, 71 feet 2¾ inches; weight in running order, 94 tons. The coupled drivin

Photograph by courtesy of the Great Western Railway.

GREAT BEAR."

inches in diameter. It is the only example of the Pacific type in Great Britain.

can succeed in compressing all his heaviest banks into one division it means that the additional locomotive power only will be required upon that section. One type of engine thus will suffice for all the easiest sections, so that the train can be kept intact over the whole 1,000 miles. On the heavy grade division extra or more powerful locomotives can be used. It may so happen, however, that the maximum grade is short, but very steep. Then, instead of attaching larger or more locomotives, a pusher engine will help to lift the train load over the short hump.

Some Sharp Gradients.

"Bunching the grades" is one of the latest developments in railway practice, short of entire elimination, and it is exercising a beneficial influence upon economical working. This idea was adopted in these islands in the earliest days of the railway era, although the majority of our engineers, when faced with sudden heavy rises, made detours in the effort to preserve the easy line. But even then they were not always successful. The North British Railway, for instance, bristles with many very heavy banks, such as the Cowlairs Incline, with its rise of 1 in 45 for 2,200 yards, and up which the trains with their double headers were assisted by a cable. The Commonhead Incline, on the same railway, has an even sharper ascent—1 in 23 for a distance of 440 yards.

The "Velocity Grade."

In many instances, during recent years, where the alignment is propitious, and where it is possible to effect a pronounced saving in the initial cost of construction without exerting any adverse influence upon the economies of operation, the principle of "rushing the bank" has been adopted. But the "velocity grade" is not viewed with general favour by engineers. It certainly offers many advantages upon a road running through thinly populated country, but is inadvisable in congested railway districts, owing to the disorganisation of traffic which must ensue when a train fails to attain sufficient momentum to rush the bank, and becomes stalled thereon until rescued by an additional locomotive.

The "Decapod."

While the evolution of the big locomotive in Great Britain has been somewhat rapid during the past few years, it has been comparatively free from any revolutionary development, such as the Mallet, produced in other parts of the world. The nearest approach to a sensation was that produced in 1903 upon the appearance of the "Decapod," designed by Mr. Holden for the Great Eastern Railway. This engine was certainly a giant of its type, and although avowedly an experiment, it created a considerable stir.

The Great Eastern Railway probably handles a heavier suburban traffic than any other trunk system in the world. By remarkably skilful scheduling and organisation, the trains engaged in this service are handled with striking celerity, notwithstanding the limitations imposed by a bottleneck outside the metropolitan terminus. The heavily congested nature of the territory served demands smart manipulation of the trains at the intermediate stations, combined with a rapidly accelerating capacity on the part of the engines. At the time the "Decapod" came upon the scene the traffic was handled by six-coupled tank engines, which, with a load of 200 tons, were able to attain a speed of 30 miles an hour within 60 seconds of starting.

Mr. Holden sought to improve upon this performance. He set out to design an engine capable of hauling a 50 per cent. heavier load, and able to accelerate to a speed of 30 miles an hour in 30 seconds. If this were achieved, then, he argued, it would be possible to increase the train service as well as decreasing the train-miles, and increasing the revenue per train.

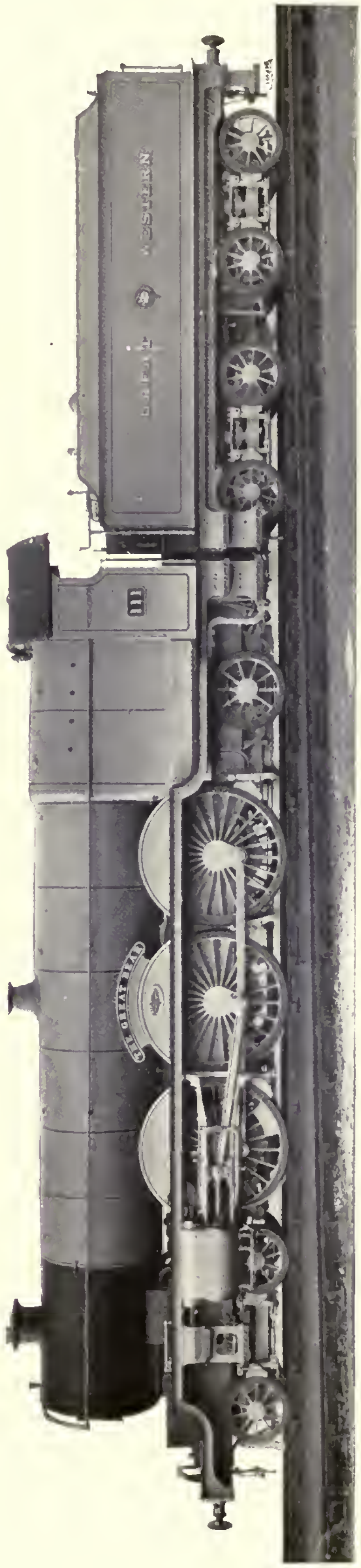
The engine was a distinct novelty to British practice, and possessed many inter-

esting features. The five pairs of coupled driving wheels 54 inches in diameter, were driven by three high-pressure cylinders having a diameter of $18\frac{1}{2}$ inches, and a stroke of 24 inches. The outer cylinders drove on the third pair of wheels, which, to facilitate the negotiation of curves, were flangeless, while the third inside cylinder acted upon the second pair of wheels. The boiler was of huge size, measuring 15 feet 6 inches in length, by 5 feet 3 inches internal diameter; it was fitted with 395 tubes of $1\frac{3}{4}$ inches diameter, which afforded a total heating surface of 2,873·3 square feet. The fire-box, with a heating surface of 131·7 square feet, had its shell spread out over the frames in the manner followed by the Great Northern and London, Brighton and South Coast Railways in connection with their Atlantic locomotives. There were three separate grates and ash pans, one outside the frames on either side, and the third between, giving an aggregate area of 42 square feet.

The trailing drivers were given a side play of $\frac{1}{2}$ inch, the coupling rods being fitted with ball and socket joints. As the cranks of the three cylinders were set at 120 degrees in relation to each other, perfect balancing of the reciprocating parts was secured. In running order the locomotive scaled 70 tons. In order to minimise the drivers slipping, especially when starting upon greasy rails, special attention was devoted to the sanding apparatus, a method of projecting the sand upon the rails by means of compressed air being incorporated.

The locomotive was subjected to searching tests under all conditions of traffic and weather, and fulfilled the anticipation of its designer. Unfortunately, however, it was found to be too heavy for some of the bridges on the system, and consequently after a brief career was withdrawn from service. It was taken back to the shops and converted into an 0–8–0 engine for heavy goods traffic.

The Great Western Railway, with its



Photograph by permission of the Great Western Railway.

"THE GREAT BEAR" READY FOR THE ROAD.

Photograph supplied by the London and North Western Railway.

THE LONDON AND NORTH WESTERN RAILWAY'S LARGEST LOCOMOTIVE, THE "SIR GILBERT CLAUGHTON."

characteristic progressive spirit, has been particularly enterprising in its locomotive development, especially during the regime of the present locomotive engineer-in-chief, Mr. Churchward. While successive designs of locomotives have been somewhat varied, they may be described as logical developments and improvements in the effort to secure economical operation with heavier loads and faster speeds. This railway has achieved a unique and world-wide fame for high speeds, and the tendency at present not only is to maintain, but to enhance this reputation.

Following the American practice, the Atlantic type was introduced for express working, and in due course this was evolved into the Pacific class, which the Great Western Railway was the first to introduce into this country, and which even to-day remains as the solitary exponent of the 4–6–2 type in these islands. In the country of its origin this class has become regarded as the standard for long-distance express traffic, where steadily maintained high speed with economy is the objective, and is undergoing widespread development, since the American engineers consider it difficult to supersede. Thus it will be seen that the Great Western Railway is well abreast of the times. At the time "The Great Bear" made its début it ranked easily as the largest locomotive in the country, a position from which it has been deposed only recently.

Its boiler measures 23 feet in length by 5 feet 6 inches at the front, and 6 feet at the back, external diameter, with a total heating surface including superheater tubes and fire-box, of 3,400·81 square feet. Each of the four high-pressure cylinders has a diameter of 15 inches, and a stroke of 26 inches, while the working pressure of the steam is 225 pounds. The cylinders drive separate coupled axles in pairs, and the valve gear is of the Walschaert pattern. Owing to the drivers being placed somewhat closer together than in the 4–6–0 class, it

vas possible to take full advantage of the
ncreased space available over the trailing
ogie in the design of the Belpaire fire-box.
n the extended smoke-box is the Swindon
uperheater, designed by Mr. Churchward.

The introduction of the superheater
epresents one of the most important im-
rovements which has been effected in the
team locomotive during the past few
ears. As is well known, water evaporates
ear sea level at 212 degrees Fahr., but the
team is not a pure gas. Minute molecules
f water are associated with it, which
epreciate the power-developing properties
f the steam, so that when it passes into
he cylinders heavy condensation ensues.
'his factor increases proportionately with
he augmentation of the size of the
ylinder. The disadvantages of this
aturated steam, as it is called, are
educed as far as possible by resorting to
igh steam pressures, up to as much as
25 pounds per square inch, in order to
et the utmost out of the engine within
he limits of gauge and weight. This in
urn demands heavy coal consumption,
ogether with adequate heating capacity in
he boiler, in order to keep the cylinders
ully up to their work. Many locomotive
ngineers deprecate this practice of using
igh steam pressures on the plea that the
vear and tear upon the fire-box and boiler
re enhanced, and consequently inflates the
ill for repairs and maintenance. On the
ther hand, other engineers, as a result of
ractical experience, oppose this conten-
ion.

Some years ago the fact was realised
hat if the water present in the steam were
liminated, then the steam could be made
o perform more useful work, as it would
e converted into a superior gas, possessed
f greater expansion properties. Under
hese conditions a smaller quantity of
team would be sufficient to accomplish
he desired end in a cylinder of given
imensions than if saturated steam were
sed. Such a development would influence

Photograph: Topical.

BRITAIN'S HEAVIEST LOCOMOTIVE: THE GREAT CENTRAL RAILWAY'S "SIR SAM FAY."

other factors. The boiler pressure could be reduced, and the cylinder increased in diameter to obtain the same or greater tractive effort, while there would be a saving in coal and water consumption, and, incidentally, in the upkeep of the boiler and fire-box.

The Superheater.

Accordingly numerous experiments were carried out to devise an efficient means for drying or "superheating" the steam. Remarkable ingenuity has been displayed in the evolution of the most suitable apparatus to accomplish this end. The steam, as it issues from the boiler, is passed through an additional nest of tubes upon which the gases of combustion from the fire play before escaping into the air. The result is that the temperature of the steam is raised to as much as 600 degrees or more, and every trace of saturation is eliminated.

The practice came into vogue first upon the Continent, where to-day over 10,000 locomotives work with superheater. Some countries were somewhat slow in adopting the idea, not from motives of scepticism, but because the comparative experiments with locomotives working under saturated and superheated steam respectively were of an elaborate and comprehensive character, in order to obtain conclusive data concerning the advantages of the new practice. The results of these experiments proved somewhat startling. Reduced boiler pressures and increased cylinder diameter were rendered feasible without impairing the capacity of the locomotive. The saving in coal per ton-mile and per train-mile ranged from 20 per cent. upwards. In other words, the fuel bill was capable of reduction by just so much by using superheated steam. Moreover, it was found that the superheated steam locomotives of a certain class were able to develop more tractive effort and to haul heavier loads at the same or higher speeds than sister engines running on saturated steam. The economy in water consumption was equally marked, while the repairs and maintenance charges were pulled down very appreciably. The possibility of hauling more tons per mile at less expense was too valuable to be ignored in these days when running expenses are mounting ever upwards. Moreover, the efficiency of the machine was improved considerably. Locomotives were able to be put to heavier and faster work than that for which they had been primarily designed.

"The Great Bear."

The superheater tubes of "The Great Bear" have a heating surface of 545 square feet. The area of the fire grate is 41·79 square feet. The coupled driving wheels are 80½ inches in diameter; the leading bogie wheels 38 inches and the trailing wheels 44 inches in diameter respectively. The tractive effort is 29,430 pounds; that is to say, if a chain were passed from the draw-bar of the engine over a pulley, and attached to a weight equivalent to the above tractive effort, the engine would be able to keep it suspended in the air when the full pressure of steam were applied. The tender carries 3,500 gallons of water, and its total over-all length is 71 feet 2¾ inches, while in running order it weighs 94 tons. This engine is used in the fastest long-distance express traffic on the system, especially on the through working of the summer London-Penzance trains, where high average speeds with heavy loads have to be handled over the heavy grades of South Devon and Cornwall.

The "Sir Gilbert Claughton."

A heavy locomotive, the ten-wheeler, or 4–6–0 type, has been introduced upon the London and North Western Railway for working the northern main lines with their heavy grades, particularly between Crewe and Carlisle, where Shap Fell has to be overcome. This is the "Sir Gilbert Claughton" class. They have been designed by Mr. C. J. Bowen Cooke, the locomotive engineer-in-chief to the system, and represent a notable departure in the

locomotive practice of this railway. This engineer has been responsible for some excellent Pacific (4–6–2) tank engines, but in elaborating this new design the trailing pair of wheels, usually placed beneath the fire-box, was abandoned.

This engine possesses many interesting features. Although there are four cylinders of 18 inches diameter, by 26 inches stroke, simple, and not compound, working, in accordance with the general trend in recent locomotive practice, is adopted. The cylinders are placed in line with the piston valves above, and all drive on the leading coupled axle. The Walschaert valve gear has been embraced for the first time upon the London and North Western system, while the fire-box of the Belpaire pattern has been adopted, together with the Schmidt superheater.

The boiler is 14 feet 6 inches in length, by 5 feet 2 inches in diameter, the centre line being 8 feet 9 inches above the rail level. The fire-box is 9 feet 6 inches in length, by 4 feet 1 inch in width outside, and has a grate area of 30·5 square feet, exceeding that of any preceding London and North Western engine. The total heating surface is 2,332 square feet, of which the tubes, $1\frac{7}{8}$ inches in diameter, represent 1,160·9 square feet, the fire-box 171·2 square feet, and the superheater complete 899·9 square feet.

The wheels of the bogie truck have a diameter of 39 inches, while the drivers are of 81 inches diameter. The tender carries 6 tons of coal and 3,000 gallons of water. The over-all length of the engine is 63 feet $4\frac{3}{4}$ inches, while the total weight is 116 tons, of which 57 tons are available for adhesion.

At the present moment the heaviest locomotive working upon British railways is the new express class which has been designed by Mr. J. G. Robinson for the Great Central Railway, the first of the six of which, the "Sir Sam Fay," was placed on show at the Ghent International Exhibition of 1913. This likewise is a ten-wheeler, 4–6–0, with inside cylinders, Belpaire fire-box, and Robinson superheater. The cylinders are $21\frac{1}{2}$ inches in diameter by 26 inches stroke. The boiler barrel is 17 feet 3 inches in length by 5 feet 6 inches in diameter. The total heating surface is 2,816·88 square feet, made up as follows: tubes, 2,219·88 square feet; fire-box, 167 square feet; superheater, 430 square feet. The grate area is 26 square feet.

The "Sir Sam Fay."

The coupled driving wheels are of 81 inches and the bogie wheels of 42 inches diameter respectively. In working order the weight of the engine and tender is 122 tons. This large and powerful locomotive has been designed especially for handling the heaviest express trains over the severe gradients of the Great Central Railway in the Midlands. Its neat symmetrical appearance contrasts vividly with the gaunt skeleton-like engines peculiar to America.

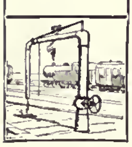
British Developments.

Thus it will be seen that, although British railways have not gone to the limits of the mammoth locomotive adopted in Continental Europe and the New World, a steady forward movement is being maintained upon gradual lines. Undoubtedly during the next few years this tendency will become more marked, seeing that British rolling stock is growing heavier, while longer trains are being brought into vogue. This development applies not only to long-distance express passenger movement, but also to the handling of the goods traffic, owing to the growing appreciation of the high-capacity goods' wagon. A few years ago the 8- and 10-ton truck reigned supreme, but the 15- and 20-ton vehicles are being adopted more extensively, especially for long distance hauls and for the transportation of minerals.

A RAILWAY CONSTRUCTION CAMP ON THE BORDERS OF THE ARCTIC CIRCLE.

The Mastery of the Glaciers

A FIGHT WITH NATURE IN THE WILDS OF ALASKA



WHEN, in 1867, the United States handed over gold to the tune of £1,440,000 to Russia, in return for the half-million odd square miles of towering mountains and yawning valleys known as Alaska, there were plenty of critics who croaked that the bargain was a good one for Russia, but a bad one for "Uncle Sam." To-day it would be impossible to find an American who is not wildly enthusiastic over the future of that far northern country. During the forty-five years the land has been under the Stars and Stripes, although it has been practically a closed book, over £70,000,000 have been taken out of it in the form of furs, fish, and minerals, in point of value. The latter easily stands first, having yielded over £32,000,000, mostly in gold, and gathered by the crudest of processes.

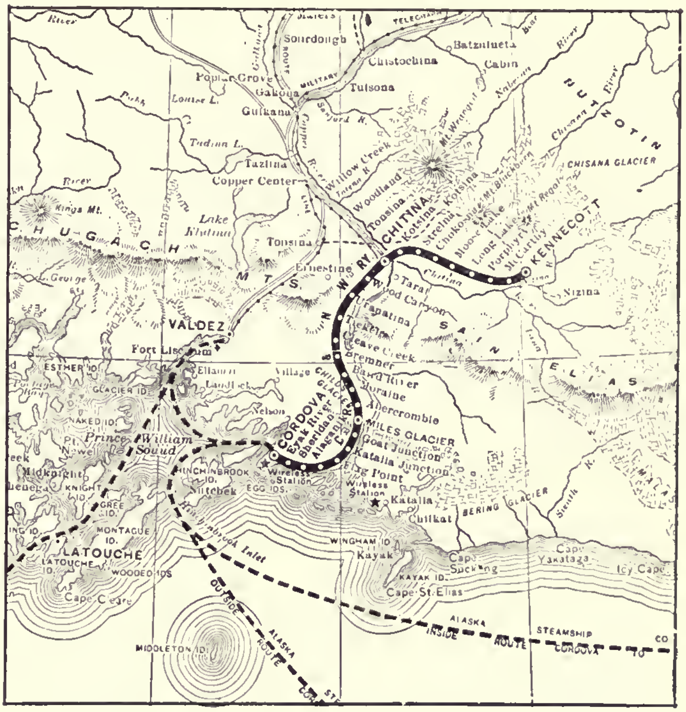
Alaska is an enormous treasure-ground, but no idea of its riches was gained until the Klondike was over-run with gold-seekers. Hardy, long-headed prospectors maintained that the mineral finds in the Yukon Territory must continue through the adjacent country to the west, and promptly they started off to scratch the mountain sides and to sift the beds of the rivers and streams. Their perseverance and temerity were rewarded. They returned to civilisation with wonderful stories about the latest Eldorado, and clinched their pictures with convincing specimens of coal, copper, and gold, which were in abundance. There was only one difficulty:

the riches were hoarded up in the interior, to penetrate which demanded untiring patience, grim determination, and hard toiling over the mountainous fence running along the coast-line.

The circulation of the stories concerning these " strikes " precipitated a northward rush from the United States. Although only a year previously the momentous stampede to the Klondike had been made, with its harrowing and dismal round of hardship, peril, privation, and disaster in the struggle over the Chilkoot Pass, the Alaskan pioneers were not to be turned from their purpose. They were eager to get rich, and quickly, too. During the months of February, March and April, 1898, it is stated that 3,000 men landed at the obscure port of Valdez, bound for the interior. It was a terrible heart- and back-breaking journey over the ever-upward zig-zagging trail across the ice of the Valdez Glacier to an altitude of 4,800 feet. Many of these gold-fever-stricken fools never had seen a glacier in their life until they caught sight of those of Alaska, which are the largest known to civilisation, and then they were staggered.

But they were so intoxicated with buoyant enthusiasm that they never paused to reflect upon the prospect. They had sleds on which they stowed their outfits, and which they considered adequate to overcome the obstacle. When the " old boys," already in occupation, told the " tenderfeet " that they must carry ropes, firewood or oil-stoves, and other necessaries with which to cook their food and to obtain their water by melting the snow or ice when camped on the glacier, the new arrivals laughed derisively. But those who disregarded the timely advice soon had occasion to repent of their assumed superior knowledge.

It was no easy going over the Valdez Glacier. The river of ice is torn and riven by rifts and chasms in all directions, and the trail wound in and out among these death-traps in the most bewildering manner.



ROUTE MAP OF THE COPPER RIVER AND NORTH WESTERN RAILWAY.

Time after time a meandering tramp of three or four miles was required to make an advance of one mile. The unusual spectacle was to be seen of villages of tents pitched at intervals on the glacier where 300 or more men were in evidence. The seething mass of impatient humanity made the distance between two camps a daily instalment of the journey.

The blinding snowstorms, gales and raw fogs contributed to the miseries and difficulties of those on the mush. A blizzard lasting 120 hours on end is by no means uncommon in these latitudes, while the frequent avalanches, rattling down the slopes, mixed tents, men, horses, and outfits in a wild mêlée. Movement during

the brilliant illumination of the day was impossible, since the snow was then softest and most treacherous and the agony of snow-blindness was encountered. Accordingly, the gold-seekers surged forward during the night under the soft gleam of the Northern Lights, when the thermometer dropped to its lowest daily reading.

Yet all this wearing of sinew and muscle was in vain. The pluck and endurance of the prospectors were mastered by the glacier; cheap transport was impossible. Castles in the air were shattered, and the greater number of the men trekked painfully and wearily back to Valdez. Those who could afford it paid for steamship berths back to Seattle; others less fortunate either stole or worked their passage southwards. A few of the hopelessly stranded lingered behind to found the town of Copper Centre, only to be ravaged by an outbreak of scurvy which decimated their ranks.

The Climate Triumphant.

A few of the hardy spirits who escaped the attacks of disease tried their luck once more after the winter had passed, and to their dauntless courage the awakening of Alaska really is due. A copper belt was found along the Chitina River, and the richness of the ore was so tempting that at last the interest of financiers became awakened. A small group was formed to work these resources, and thus the opening up of Alaska began in true earnest, as the provision of facilities to gain the mineral district was the first consideration.

Discovery of Copper.

An organisation, the Katalla Construction Company, was formed by the alliance of Messrs. J. P. Morgan and the Guggenheims, who control the smelting industry of the United States, to complete a railway into the interior and to found a port upon the coast. It was recognised that the forging of the essential communicating link would bristle with searching difficulties and would cost an enormous amount of money, inasmuch as the Chitina River district lies on the east side of the towering mountain range which runs parallel to and hugs the coastline. Moreover, owing to the numerous spurs running from this great backbone to the water's edge, where they break off in precipitous cliffs, the natural facilities for handling vessels, in relationship to the route of the line into the interior, are very few and far between. There was only one point where the Saint Elias and Chugach Mountains could be pierced economically: that was the gorge through which the tumultuous Copper River hurries and scurries to the sea. It is not a river; it is merely a headlong rush of water, foaming through canyons, and wandering aimlessly over low-lying nooks in the mountains.

The selection of the tide-water terminus was the first question, and the syndicate experienced a lively hunt and dismaying rebuffs in this connection, because the discovery of a suitable harbour proved as elusive as the will-o'-the-wisp. As Valdez had come into such prominence with the gold rush of '98, the engineers thought it would be an ideal situation for their purpose. A large sum of money was expended in improving the port, when suddenly it was announced that the grade from that point through the mountains would be too heavy. Accordingly Valdez was abandoned. Then it was decided to secure a point at the mouth of the Copper River itself, and as Katalla, on the south side of the estuary, offered every inducement, harbour-building operations were commenced there. A breakwater was thrown out to enclose a large area of water in which ships might unload and load. When £200,000 had been expended it was found impossible to secure a sufficient depth of water, while complete protection could not be secured against the heavy storms experienced along this coast-line. Indeed, one tempest played sad havoc with the

Selection of a Terminus.

ONE OF THE WOODEN TRESTLE BRIDGES ACROSS THE COPPER RIVER.

works already completed, and in face of the unequal odds Katalla shared the same fate as Valdez.

A third decision brought the terminal on the northern side of the Copper River estuary, and here the American interests received a startling check, which at the time appeared to be more insuperable than the hostility of Nature. While the Katalla Construction Company's engineers had been scouring the coastline, and probing the mountains for the easiest route for a railway, British enterprise had won. A railway builder, Mr. W. J. Honey, and Mr. E. C. Hawkins, an experienced engineer, with British financial backing, had carried through the White Pass Railway in the face of tremendous odds, and had learned from bitter experience just what railway construction through such heavy country entailed. When the line to the Klondike was completed, the builder and the engineer, supported by the same financial interests, having heard of the Morgan-Guggenheim intentions in Alaska, quietly moved northwards to achieve another conquest. Unostentatiously they ran up and down the Copper and Chitina Rivers, and discovered not only the easiest and cheapest, but also the only practical, location for a railway, as well as an ideal terminus on the seaboard with plenty of deep water, at Eyak Village, near Cordova. The Katalla Construction Company finally seized Cordova for their terminus, and it proved suitable; but when they endeavoured to run up the Copper River they found themselves balked by the rival British interests.

THE ROAD THROUGH THE DISMAL TUNDRA OR MUSKEG.

When the Americans realised the situation seven miles of line were built, and there was every indication that toil would not cease until the Bonanza Mine was gained. The British owners were prompted to push ahead with their work, because they knew only too well that if the American syndicate were determined to own their own railway to the mines—well, they would have to buy out those already in possession. It seemed as if the Americans were doomed to be outwitted by British shrewdness and enterprise, as they had been in connection with the White Pass Railway.

A fight was impossible, as the rival was entrenched too firmly. The Morgan-Guggenheim combine accepted the inevitable and offered to buy out the British interests. A deal was effected, the latter securing a tangible hold in the American undertaking. Mr. Hawkins was made vice-president of the Katalla Company, while a new subsidiary concern, the Copper River and North Western Railway, was created, with Mr. Hawkins as general manager and chief engineer, while Mr. Honey was given the contract to build the line.

The railway is of standard gauge, and after it rounds the tongue of land forming the northern shore to the Copper River estuary, picks up the river proper at Flag Point, the waterway being hugged for 104½ miles to Chitina. Then it swings to the east, to follow the Chitina River as far as Kennecott, where the Bonanza Mine is situated.

This railway runs through some of the wildest, most repelling country it is possible to imagine. Forbidding canyons, through which the water thunders savagely, stretches of swamp, toes of glaciers, water-logged alluvium, and mountain shoulders were encountered in turn. At places the fight put up by Nature was of the sternest character, and the engineers were not able to get through with their narrow shelf on which the metals are laid for less than £50,000 per mile. Money had to be poured out at the rate of £15,000 per mile for 25 miles, while another section averaged £20,000 per mile. Thousands of pounds literally vanished in smoke, because hundreds of tons of giant powder went up to blast the narrow causeway through the

BUILDING THE GREAT STEEL BRIDGE ACROSS THE COPPER RIVER.
One of the most expensive bridges in America. In the photograph water is seen flowing over the ice of the frozen river after a sudden thaw.

hard rock of the mountain humps. Individual blasts of 15 and 20 tons of explosive were quite common, and when work was in full swing at the point where the going was hardest and heaviest, an army of 1,500 men found employment, driving their way relentlessly forward yard by yard.

In plotting the line, it was decided to keep the gradients down as far as possible. This was a laudable proposal, but difficult to fulfil in a land where the forces of Nature have carried out their work in a mad, haphazard manner. It required money: if this were forthcoming the engineer could be trusted to achieve the desired end. But the question of curvature was not solved so easily. The river twists and turns amazingly, and as the route had to follow the waterway, the engineer was not given much scope to straighten out these sharp bends unless he embarked upon a wholesale mountain-moving campaign.

The Question of Curves.

The labour question was perplexing. Men accustomed to heavy mountain-railway building were difficult to obtain. Down in the Western States railway expansion was exceedingly active, and the demand for workmen was so keen and well paid that labour was not compelled to go northwards to suffer virtual imprisonment, the Arctic blasts, low temperature, and other perils for a few dollars per day. The contractor, as he was working upon a time-limit, at one time required 4,000 men. His appeal was answered by a handful of scores! The rigours of the climate played sad havoc with all but the most hardened and experienced toilers. Many men, after a brief experience, had to abandon their task and return to more congenial climes. The southern European races, although for the most part excellent navvies, could not tolerate a country where the rainfall averages 120 inches per annum, where the thermometer sinks to 60° below zero in winter, where the snowstorms rage for days without ceasing, and where the wind rushes with such velocity as to beat through the thickest clothing as if it were only muslin. Scandinavians were the men most naturally fitted to the task; they are acclimatised to this latitude, and are born workers in rock.

Labour Difficulties.

The "muskeg," or bog-land, was exasperating. In winter, under the wand of King Frost, it becomes as solid as a rock to a depth of some 20 feet; in summer, owing to the power of the sun, it is transformed into a half-set jelly, which, although it will support the weight of a man, sucks down anything heavier. Huge piles were driven into this plastic mass, and the spaces between the legs, which were held together with cross-pieces, were loaded with stone blasted out of the rock cuttings. Fortunately, in Alaska this tundra is not able to thaw out entirely: the heat of the sun cannot penetrate to a depth of more than 10 feet or so. The result is that the bottom of the bog is eternally frozen, so that the piles when driven downwards to a foot or so below the frost mark secured a firm hold.

The "Muskeg" Problem.

While the Alaskan summer is delightful, with the temperature hovering about 94° in the shade and the sun shining for nearly twenty out of the twenty-four hours, it brings its own peculiar discomforts. The flies are an implacable enemy. The muskeg forms an ideal breeding ground for mosquitoes, while the little black fly and the caribou-bug are equally vicious. They can only be kept at a distance by "smudges"—smouldering fires of damp leaves emitting dense clouds of smoke—but these are impracticable when navvying. A pungent, oleaginous dressing—"fly dope"—applied to the face and hands secures respite from their attacks until the odour has evaporated, but this is an indifferent makeshift. The toilers

The Mosquito Scourge.

only secured relief by encasing their heads in finely meshed muslin nets, resembling flexible meat-safes, while their hands were encased in large gauntlets. At night they were compelled to sleep in mosquito-proof nets.

The summer brought added perils in the form of snow, rock, and land slides. The fierce heat of the sun melts the heavy blankets of snow that clothe the mountain tops, causing large masses to slip. Once set in motion, they never stop until they reach the depths of the gorges below. The rock and land slides were equally fearsome. With a rattle and a roar, as if a gigantic artillery duel were in progress, huge boulders, hillocks of loose debris, trees, and what not come careering down the slopes with terrific fury, setting up tornado-like winds in their train and spreading destruction on every hand. The heavy melting of the snows also contributed to the turbulence of the rivers and creeks, the waters of which rose and fell several feet within a few hours. When the Copper River is swelled by these enormous additions of water, it rushes along with the fury of a mill-race, bearing the gaunt stumps of towering trees on its bosom, and carrying away the soft, friable parts of the banks with the greatest ease, only to pile all in unsightly humps, ridges, and banks at the delta, where the river straggles over a wide area. The engineers, therefore, were compelled to lay their pathway well above the fiercely scouring force of the river, otherwise its life would have been brief.

Land Slides.

While the path of the railway for the most part lies along a shelf hewn and torn out of the mountain flanks, which tumble into the river almost with the steepness of a plumb-line, its advance was disputed by another formidable natural obstacle—glaciers. From the banks of the Copper River may be seen some of the largest and most magnificent active ice rivers in the world. Two of these—Miles and Childs Glaciers—come to the water's edge at a point 40 miles distant from Cordova, and are wonderfully picturesque and impressive. Childs Glacier in particular is enthralling. It rises from the water in a solid scintillating cliff to a height of 300 to 500 feet, while from one end to the other of its prismatic face is a distance of three miles. Throughout the livelong day during the summer the "calving" of icebergs is in progress, and the spectacle is wonderful, as the large detached masses tumble into the water with a roar, sending immense waves rolling across the river and huge columns of spray into the air. To avoid this obstacle the railway swings across the river over a huge bridge.

At one point an unprecedented piece of railway engineering has been consummated. The line runs along a shelf which has been cut out of the dead end of the stagnant Allen Glacier, where the *metals are laid upon the ice for a distance of five miles*. At first sight the situation does not present many of the attributes of a river of ice, inasmuch as the end of the glacier is completely covered with dense scrub and other debris. But when the rock-hogs attacked the section they blew out huge chunks of ice in their blasts laying bare the toe of the glacier. The ice river was plainly discernible alongside the track for two years afterwards. Someday perhaps the Allen Glacier will suddenly return to life and push the railway into the river. Then the engineers will have to throw another bridge across the wide waterway to gain the opposite bank. No apprehensions are entertained on this score at present, however, as the ice river has evidently been quiescent for many score years past.

A Railway on a Glacier.

While winter brought a relief from the assaults of the flies, and rendered movement somewhat easier by snowshoe and sled over the snow-carpeted ground and frozen waterway, the workmen had to keep on

THE BIG STEEL BRIDGE OVER THE COPPER RIVER BETWEEN MILES AND CHILDS GLACIERS.
Childs Glacier, 300 feet in height, is seen in the background; icebergs in the foreground.

the move and encase themselves in heavy woollen clothing to keep the blood circulating through their veins. When the temperature hovers around 70° below, and the Arctic wind is blowing keenly, the severity of winter's rule is felt. The Copper River valley is a funnel through the range, and the wind, being forced into a narrow space, tears along with fearful velocity. At times the men could not keep their feet, and swinging heavy hammers, guiding the descent of massive pieces of metal for a bridge, or putting the rails shipshape, whilst endeavouring to maintain one's balance, is somewhat precarious. Attempts to ease this situation were made by erecting timber screens to act as "breakers," but the Arctic gale caught hold of these defences and splintered them to matchwood. Now and again a new fall of snow would come sliding down the mountain slopes, heading straight for the constructional forces. There was a shrill cry and a wild scamper to safety until the snow had gone. Then the men returned, and with their shovels diligently toiled to extricate the railway and trucks.

While the location of the line through the rugged narrow canyons, where the engineer had to seize every available foot of ground to receive the metals, was exciting work, it is the bridges which catch the eye, especially those over the Copper and Kuskulana Rivers. Both are great achievements, completed under the most exciting conditions. But in addition there are numerous other erections of this character, wrought in concrete, steel and timber, according to circumstances, with here and there a fine example of wooden trestling.

Bridge-building commenced ere the engineers had got into their stride, and had picked up the mouth of the river. It is an ill-kempt estuary sprawling over the whole width between the two lofty banks, which fall back somewhat at this point. The river, which in the course of its mad rush to the sea collects vast quantities of silt, is forced to disgorge its ill-gotten gains at this point, and accordingly throws it up in dreary banks and ridges, intersected with numerous channels. These flats are the home of millions of wild fowl

of all descriptions, and as food is available in plenty, they constitute ideal breeding grounds, the low thick scrub providing excellent protection. As the delta is practically a quagmire for the whole of its width, a large bridge of nine spans, for which over 4,000 tons of steel were required, had to be built to carry the line from bank to bank. At first, however, a timber trestle was thrown across the gap to enable the railway to be pushed forward, the permanent steel bridge being built at leisure.

When the engineers had penetrated about 22 miles up the river, their advance was disputed by the towering ice wall of Miles Glacier on the left bank, while on the right bank loomed Childs Glacier, the bulb ends of these two mighty rivers of ice being almost opposite. A swing across the waterway was imperative. A point about three miles below the glacier was selected for the crossing, and as the river here widens out to form a lake, it was seen that a teasing and tedious piece of work was unavoidable. As construction on the opposite bank could not be held up until the bridge was completed, a ferry service was established on the waterway, whereby materials and men were transferred from bank to bank. By this arrangement the engineers were given plenty of time to reconnoitre the situation and to lay their plans so as to secure complete success.

As the bridge runs parallel to the face of the ice wall, and about three miles below its foot, the engineers were confronted with a somewhat perplexing problem. The Alaskan glaciers are particularly active, and an advance of 5 feet per day is by

NOT A CANAL, BUT THE RAILWAY FLOODED.

After the rotary snow-plough had passed a glacial stream broke through, and, filling the snow cutting, rendered the line impassable.

no means abnormal. In these circumstances icebergs are calved by the hundred, and while the river is open come sailing down the waterway in a never-ending procession. It is a majestic spectacle for the visitor, but this phenomenon was regarded with misgivings by the bridge-builders. When an iceberg, weighing several hundred tons, is swept along at a speed of eight or ten miles per hour, woe betide any object which it may chance to strike. If this happened to be a bridge pier, well, the handiwork of man would offer a very insignificant resistance and present a sorry sight after the collision.

Glacier Observations.

One whole summer was devoted to observing the "calving" and "flow" of the bergs, the channels they favoured, as well as their varying velocity, size, and behaviour when they were caught up by the scurrying river. Some of the bergs were observed to be of immense dimensions, towering 20 feet and more out of the water, and although their advance was braked, owing to the lower extremities dragging along the river bed, yet they kept going at a steady seven miles an hour. The disintegration of the glacier and the run of the bergs continued incessantly from June 1st to November 1st, when winter descended upon the scene.

The menaces only could be compassed by building a huge bridge of a total length of 1,550 feet, divided into four spans. The problem was the disposition of the piers, but the observations had revealed the presence of two bars in the stream which the bergs skirted, and very seldom fouled. By seizing these sand-bars as the points for the piers, the bridge was divided up into spans of the following length—450 feet, two of 400 feet, and 300 feet respectively. It was decided that the span over the main channel should be a cantilever, the heavy spans on either side thereof being the anchor arms. A "camel-back" design was adopted for the spans, which, owing to the bridge being placed athwart the river, and thereby being exposed to the full broadside pressure of the hurricane winds, were designed to withstand a pressure of 40 pounds per square foot when loaded, and 60 pounds per square foot unloaded.

"Ice-Resisters."

By setting the piers on the sand-bars, although the danger from bergs was avoided, another equally serious peril was courted—packing of the ice. In winter the river freezes to a depth of 7 feet, and when the thaw comes there is a wild mêlée. The ice splinters in all directions, and the floes, caught by the suddenly awakened river, are tossed hither and thither and hurried down stream. But their progress is impeded by other floes which have not started on their ride to the sea, and these decline to be driven prematurely. Consequently the skeltering ice behind piles upon that in front, forming big jambs. As the river thus becomes blocked, the level of the water behind the pack rises, setting up an enormous pressure. The packing of the ice is accentuated by the existence of any obstacle in the waterway, such as one of these bridge piers would offer, and it would be difficult to contrive a support which would effectively resist being pushed over bodily. To remove all possibility of this calamity, "ice-resisters" were built around the piers, and these, strengthened by iron rails weighing 56 lb. per yard, which were used in constructional work, offer a complete defence against the push of the ice. Foiled, the broken ice grates and grinds itself to pieces in impotent rage against the defences, until finally it is swung to one side and carried down stream.

Work was commenced in the winter, when the river, at its lowest, was rendered quiescent by its icy armour. The men toiled laboriously in a temperature 70° below zero, bringing up the heavy caisson machinery, facing the knife-edged Arctic

blasts, and struggling desperately against blinding blizzards. Nearly five months were occupied in this preliminary task, and the sleds were kept going continuously. Delays were frequent. Now and again there would be a galling hold-up owing to a snow slide hitting the railway and burying it to a depth of 30 feet or so, hindering the movement of the trains until the obstruction was shovelled away.

THE KUSKULANA BRIDGE
The river thunders through the gorge 175 feet below the line.

Labour was crowded on during the reign of the ice-king, but it was exasperatingly slow cutting holes in the ice to permit the heavy wooden piles that constituted the falsework for the anchor spans to be driven home. Saws were useless, with ice 7 feet thick, so steam jets were played upon it, the pile slipping gradually downwards as the hole was melted.

When work was at its height, during the winter of 1910, operations were thrown all sixes and sevens. The weather, with its characteristic eccentricity, broke, a warm spell setting in at the very time when the country should have been firmly gripped by frost. The thaw was accompanied by heavy, driving rain. The armour of the river became submerged by some 2 feet with freezing slush, and this superimposed weight caused the ice, as the thaw progressed, to sink to a lower level. Childs Glacier awoke and burst into unwonted activity, by slipping forward at the rate of some 10 feet per day.

This unexpected development precipitated an alarming situation. By the constriction of the channel the water was backed up, and the enormous pressure thus exerted upon the under face of the icy covering burst it in all directions. The falsework, which happened to be in the way of the movement, suffered heavily,

the massive piles being forced out of position and the cross-bracing torn from its fastenings.

The thaw lasted about a fortnight, when winter again settled down to its humdrum condition; but it broke up earlier than was expected. The bridge-builders were caught at a disadvantage. The ice began to heave under the swelling volume of water beneath, and in so doing lifted the falsework of the first two shore spans on the south side of the river. As some of the steel had been set, disaster seemed imminent. The men stopped erecting and concentrated their energies to alleviating the ice pressure with steam jets and chisels welded to the end of short lengths of 1-inch piping. As the steam caused the ice to release its hold upon the timber the men plied their chisels for all they were worth, clearing the hole so as to permit the piles to sink back again into their beds. Large gangs toiled laboriously night and day in this unequal conflict, and at times the situation became thrilling. There would be a creak and groan! The ice would be seen to lift. The workmen hurriedly dragged their tools to the spot and played the screeching live steam upon the "heave," so as to bring the steelwork which had been disturbed above back to its place. Sometimes they were successful; at others they were not. In the latter event the "bridge-flies" swarmed the superstructure and corrected the movement by the aid of jacks, wedges, and blocks resting beneath the girders.

A Fight with the Ice.

While this work was in full swing, and the men were congratulating themselves that they had frustrated the effect of the ice, Miles Glacier started moving. The advance of an ice ram over 50 miles long by 3 miles wide, and some 300 to 500 feet high, into a neck of water, is bound to precipitate some unexpected contretemps. In this case it caused the water in the river to burst through its icy bonds, the ice being smashed into huge fragments, which were caught up and hurled against the falsework. The hammering was so heavy that a part of the timbering was detached and swung round, when it collapsed. The men fought like demons day and night incessantly throughout a solid week, and just as they were commencing to gain the upper hand, after a certain amount of damage had been wrought, Childs Glacier entered the combat and bombarded the work with icebergs, which it threw off one after the other with startling rapidity. These monsters, becoming entangled with the piled ice, imposed tremendous pressure upon the bridge. The structure appeared to be doomed: the workers were helpless, and the engineers were prepared for a gigantic smash, although they never ceased their efforts to avoid catastrophe. Just as suddenly the situation cleared: the river opened up, and carried away the pack-ice and bergs in a wild rush. The bridge was saved. The damage wrought was repaired quickly, and before the next winter set in the structure was completed after a round £100,000 had been spent.

The Kuskulana Bridge is of quite a different character. When the engineers swung at right angles from the Copper River to push westwards along the Chitina River valley to gain Kennecott, their path came to the brink of a deep ravine—a crack in the earth's crust with precipitous rock walls 175 feet deep and 190 feet wide, through which tears the Kuskulana River. After completing the surveys the engineer decided to span the gap with a massive deck truss-bridge, 525 feet long, divided into three spans, the longest of which, of 225 feet, immediately over the gorge, was to be erected on the cantilever principle.

The Kuskulana Bridge.

The engineering party entrusted with this task left Cordova on April 1st—an auspicious date—1910, intending to travel by train to the railhead, which was rapidly approaching the gorge. They carried all

their requirements, so that work could be commenced the instant they arrived at the site. But the train had gone only 22 miles when there was a breakdown. The line was buried beneath a heavy snow-slide. The rotary plough had been bucking into the obstacle, but the revolving scoop had struck something it was not designed to handle and was thrown out of action. The track was 2 feet under water, a glacial stream having broken into the canal-like cut made by the plough. This had frozen almost solid, so that the train was stalled hopelessly, even if the snow-plough were repaired. Sooner than suffer delay, the party tumbled out of the caboose, donned their snow-shoes, loaded up their small sleds, and toiled over the snow and ice for a distance of nearly 80 miles. Hard on their heels came a labouring gang of fifteen men, who dragged their equipment on sleds over the whole 100 miles of arduous, zig-zagging, back-breaking trail between Miles Glacier and the Kuskulana Gorge. The constructional material itself had been brought up previously by small steamers, which at great risk penetrated almost to the bridge site.

Preliminary Measures.

As the bridge was to be built simultaneously from both sides of the ravine, the initial task was to establish a means of conveying the material across the chasm. For this purpose a cableway was erected. A narrow suspension bridge also was thrown across the gulch near the site to enable the workmen to pass from side to side.

The main span is supported at either end upon a steel tower, for which deep pits had to be sunk to receive the concrete foundations. This was painfully tedious work. The tundra was frozen as hard as the rock near by. The warm sun playing upon the muskeg thawed the surface to a depth of 6 inches or so. This was removed within the area required, and a fresh frozen surface exposed to the sun. When this had thawed out it was excavated in turn, and a further section allowed to melt, this process being continued until rock was reached. Progress was very slow, as three days had to be allowed to permit the uncovered frozen surface to thaw out to the depth of the spit of a spade. When the rock was reached, it was found to be split in all directions by frost, and accordingly the foundations had to be taken down 10 feet more than had been anticipated.

How the Steel-work was Fixed.

While this work was in progress the timber falsework for the shore spans was pushed forward, and by the time the winter came round everything was ready for placing the steel in position. Two immense travellers were set up, as the central section was to be built upon the over-hang principle. As the railway had reached the gorge by this time, the material was brought to the brink, and the cable-way was kept going hard, transporting 540 tons of steel-work, while one traveller and four steam engines for hoisting purposes were swung across the ravine.

How Steam was Supplied.

The arrangements for supplying and distributing the power to the various working positions demanded considerable ingenuity. Owing to the depth of the gorge, the water for steam raising purposes could not be drawn from the Kuskulana River, all supplies in this connection being brought in by train. The water was stored in a tank which was fitted with steam pipes to protect it from frost. As the men on the opposite side of the gorge required water and compressed air, a water-pipe, flanked on either side by live steam pipes, thickly and tightly bound in hay, was laid across the footbridge from the main power station. Although hay is an excellent insulator, it scarcely suffices for a temperature ranging at anything between 30° above and 60° below zero, so that delays frequently occurred from the water-pipe freezing.

The erection of the steel-work com-

menced on November 8th, 1910, by which time the permanent constructional camp had been moved from Miles Glacier to Kuskulana upon the railhead reaching the gorge. The anchor spans were completed very quickly, when 50 tons of rails were packed on the shore extremity of each to act as counterweights during the building of the cantilever span. The heavy travellers were moved outwards, and the material was brought out to them over a temporary track laid upon the lower deck of the bridge. Once the engineers got well started work went forward merrily. The only serious handicap was the shortness of the Alaskan winter day, there being only about three hours between sunrise and sunset in December. The travellers crept towards one another through the air until they met over the centre of the gorge. Then the mass of steel was manipulated so as to bring the ends in line and to admit the insertion of the last panel to connect the two arms. This delicate operation was successfully consummated with the thermometer registering 40° below zero, the travellers were dismounted, and on January 12th, 1911, the first train moved across the structure. The Kuskulana Gorge was bridged within nine months of the engineers' arrival upon the spot, while the 525 feet length of steel forming the structure was set in position within two months —a remarkable achievement under the peculiar and arduous conditions prevailing.

While the Flag Point, Copper River, and Kuskulana bridges constitute the outstanding examples of this form of engineering upon the Copper River and North Western Railway, there are 311 small timber trestles. After the Kuskulana Gorge was conquered, the railway advanced to Kennecott, the inland terminus, 195½ miles from Cordova, the metals being carried to the doors of the Bonanza Copper Mine. By the time the last rail of the Copper River and North Western Railway had been laid some £3,500,000 had been spent.

THE END OF THE TASK: LAYING THE METALS AT THE BONANZA COPPER MINE.

STEAM *v.* ELECTRICITY.

The rapid strides made in recent years in electric traction suggests the ultimate displacement of steam power. One of the latest British types of steam locomotive is here shown in comparison with an electric "flyer."

By courtesy of Messrs. Siemens Brothers & Co., Ltd.

THE SIEMENS ELECTRIC RAILWAY AT THE BERLIN EXHIBITION, 1879.

Steam *v.* Electricity

THE INCEPTION AND DEVELOPMENT OF THE ELECTRIC LOCOMOTIVE

AT the present moment the most absorbing problem in railway operating circles is whether the steam locomotive, which has accomplished so much during the past century, shall be superseded by electricity. During the past few years the question has been debated very vigorously, and already many remarkable developments have been accomplished, while others of a more daring character are in course of consummation or are under contemplation.

From the activity which is being manifested at the moment, the average individual might be disposed to think that the electric railway is a new idea, or rather is a twentieth century movement. This is far from being the case. The propulsion of vehicles by electric energy aroused attention shortly after George Stephenson had demonstrated the possibilities of the steam locomotive at Rainhill.

The fact that electricity was destined to play an important part in railway operation was shown conclusively for the first time by a British experimenter, Robert Davidson, of Aberdeen. In 1842 he built an electric car which ran on the Edinburgh and Glasgow Railway, now incorporated with the North British Railway, which, laden with passengers, attained a speed of 4 miles an hour. Davidson's idea, however, was premature. The electrical energy was drawn from batteries, and at that time such a system was hopeless. Moreover, commercial interests were riveted too closely at the time upon the steam locomotive. Still, Davidson was the pioneer; he was the first to demonstrate what could be done with electricity as a means of moving wheeled vehicles along the steel highway.

The subject of electric traction occupied the minds of the savants in both hemispheres for many years, but little was

A THRILLING EXPERIMENT: A NECK-AND-NECK RACE

In order to obtain comparative data concerning the two systems of operation the New York Central Railroad
away from its rival. The steam train is travelling

BETWEEN ELECTRICALLY AND STEAM DRIVEN TRAINS. *By permission of the British Thomson-Houston Co., Ltd.*

carried out a series of runs with trains of identical weight. This photograph shows the electric train drawing at 60 and the electric train at 61·6 miles per hour.

accomplished until Werner von Siemens, the famous German electrical scientist, devoted his energies towards the solution of the problem. In 1870 a decided step forward had been made by Gramme's

By courtesy of Messrs. Siemens Brothers & Co., Ltd.

THE 3-HORSE-POWER ELECTRIC LOCOMOTIVE INVENTED BY WERNER VON SIEMENS IN 1879.

invention of the ring armature; thence the dynamo underwent rapid development.

Siemens' electric locomotive was unpretentious. It comprised a 3-horse-power motor mounted on a truck with the drive to the axle through spur gearing. At the Berlin Exhibition in 1879, a short line, about 600 yards in length, was laid down, and along this road the locomotive hauled three carriages, capable of carrying 30 passengers, at a speed of about 4 miles per hour. The current was drawn from a third rail laid between the track rails, and the latter acted as the return to the dynamo. This primitive electric railway proved a strong draw among the visitors to the Exhibition, while it created intense interest among scientists and engineers.

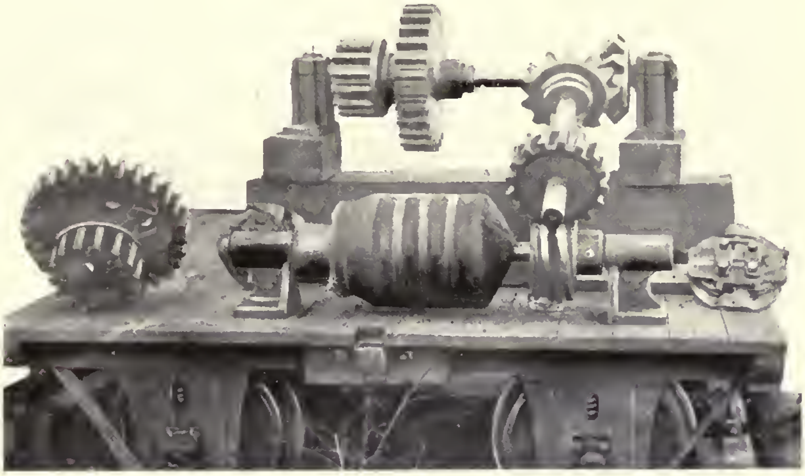
This Siemens electric railway, although regarded as little else than a "side show," virtually inaugurated the electric railway era. For the first time it was recognised that a possible rival to the steam locomotive had arrived. Edison was attracted to the problem, and he laid down a short length of experimental track near his laboratory at Menlo Park. His engine likewise was very primitive, comprising a flat truck on which the dynamo was installed.

In co-operation with Henry Villard, who was President of the Northern Pacific Railroad, another line $2\frac{1}{4}$ miles long was built at Menlo Park. Edison designed a new electric locomotive of standard gauge capable of hauling three vehicles. As narrated elsewhere, Villard, from the moment when he first saw the Edison electric locomotive, was convinced that this system was destined to play an important part in the economics of railway operation, and he supported Edison whole-heartedly.

Before Edison had completed his second experimental railway, electric traction had entered upon the commercial phase in Great Britain. On August 26th, 1880, a company was incorporated to construct a railway 6 miles long from Portrush, in County Antrim, to Bushmills, to be worked by electric power. Simultaneously Mr. Magnus Volk received permission to lay a narrow gauge railway along the beach at Brighton. This was opened for traffic on August 2nd, 1883, shortly after the Irish line, and it is historically interesting as being the first English electric railway.

Once the possibilities of electric traction became appreciated—in which development the Old World led the way—curiously enough, the idea of adapting it to street tramways became the first and foremost consideration. Its application to the railway languished considerably for many

years, but the dawn of the twentieth century revived the idea, especially in those countries deficient in fuel resources, but possessed of incalculable sources of energy in the form of waterfalls, such as Sweden, Switzerland, and Italy. Millions of horse-power were running to waste.



THE GEAR OF EDISON'S FIRST ELECTRIC LOCOMOTIVE.

Therefore it was only natural that such countries should attempt to elaborate schemes for the harnessing of this water-power, and its transmission over vast distances to points where it could be used. But the conditions of railway service differed very materially from those incidental to street tramways. There were many peculiar problems inherent to the former which did not arise in the latter development. Accordingly, it became necessary to embark upon elaborate and costly experiments for the purpose of determining the means of meeting the situation most effectively and economically. Unless a decided advance could be made upon steam locomotive practice from every point of view, then electrical operation would be difficult to bring about. The railway managing element is notoriously conservative, and argues with no other weapon beyond pounds, shillings, and pence.

The most striking tests carried out in this connection were those made by the New York Central Railroad in conjunction with the General Electric Company of Schenectady. This railway was the only one at that time which ran direct into New York City, but the terminal had to be approached through a bottle-neck of tunnels. These, becoming choked with the steam and smoke from the steam locomotives, rendered movement somewhat dangerous, because the drivers experienced great difficulty in picking up and reading their signals. These conditions ultimately precipitated a terrible accident, after which the company determined to electrify the whole of its entrance into the city without any further delay.

THE CONTROLLER OF EDISON'S FIRST ELECTRIC LOCQMOTIVE.

This initial step, however, was one of considerable magnitude. It comprised the electrification of the main line for a distance of 34 miles from the terminus, together with 24 miles on another—the Haarlem—division. The two sections, however, represented two totally different services, the first-named being express, and the latter local traffic. This meant that the electric locomotives would be called upon to haul the trains a matter of 34 miles, and they would have to be equal at least in speed and other essentials to the steam locomotives. The decision to move the heaviest express trains by electricity was something entirely new; the authorities had no precedents to assist them. They had to find out everything for themselves. Under these circumstances they decided to carry out comprehensive and conclusive investigations.

Experimental Steps.

For this purpose six miles of a fourth set of metals near Schenectady, over which the steam trains ran, was electrified to serve as an experimental track. The stretch of selected line was practically straight, the curvature being extremely easy. The gradient was slightly adverse to westward movement, rising from 5 to 17 feet per mile from the eastern end of the section to a point between the fourth and fifth miles, whence it dropped at 6 to 19 feet per mile to the sixth mile. The track was overhauled and well ballasted, so as to permit of speeds up to 70 and 80 miles per hour. A third, or conductor, rail was laid down, and alternating current was transmitted from the generator at 11,000 volts to a sub-station placed at a half-way point, where it was stepped down (and converted) to 600 volts direct current, at which pressure it was delivered to the third rail.

The locomotive used for the test was to be capable of pulling a load of 875 tons—the maximum weight of an express train—at speeds ranging up to 65 miles per hour. The conditions were somewhat exacting. Seeing that the weights of the express train vary, and that some fifty locomotives of on type were to be supplied for the service, it wa decided to adopt the multiple unit system o control. This arrangement gave extrem flexibility. By this means two locomotive can be coupled together and operated fron the leading engine as a single unit. Suc a "double-header" would suffice for th heaviest trains, while for trains up to 45 tons a single engine would be ample.

The Electri Locomotive.

The locomotive was of the 2–8–2 typ there being a leading and trailing bogi and four pairs of coupled drivers. Each axle was fitted with a motor having a normal rating of 550 horse-power, representin an aggregate of 2,200 horse-power, thoug at starting the engine was capable o exerting 3,000 horse-power. The control ling apparatus was in duplicate on eithe side of the cab, and was so arranged as t conform as closely as possible with th position of the driving control in the stean locomotive.

Hour after hour, for day after day through three months this locomotive wa run up and down the experimental track hauling loads of varying weights. Minut records were kept of every run, so as t afford complete information upon an possible issue which might be raised b the railway authorities.

The Opponent Compared

The supreme test was made on Apri 29th, 1905, when it was decided to obtai comparative data of electric and steam haulage. The electric locomotive was pitted against one of the latest and most powerful steam locomotives engaged in the expres service, the two being run side by side The steam monster was of the Pacific type with cylinders 22 inches in diamete by 26 inches stroke, having 3,757 squar feet of heating surface, measuring 67 fee $7\frac{3}{4}$ inches over all, and weighing, complet with tender, 171 tons, of which $23\frac{1}{2}$ ton were concentrated on each driving axle

Photograph by permission of the British Thomson-Houston Co., Ltd.

THE TRIUMPH OF THE ELECTRIC LOCOMOTIVE: DRIVING THROUGH A SNOWDRIFT.

In the early days of electric operation it was stated that snow would prove an insuperable obstacle. To disprove this contention the New York Central Railroad drove a train through heavy drifts which had piled on the track after a blizzard.

The electric locomotive measured 36 feet 11¼ inches over all, and weighed 100½ tons, with 17¾ tons concentrated on each of the four driving axles. Thus the electric locomotive was 30 feet 8½ inches shorter and weighed 70¾ tons less than its steam rival, while the difference in axle weight was 5¾ tons in its favour.

The first run was made with a trainload of eight coaches. The total load of the steam train, including the engine, was 513 tons. Owing to the lesser weight of the electric locomotive, the latter's train was loaded up with 70¾ tons so as to bring its weight approximately to that of its rival.

First Point to Electricity.

The two were lined up side by side, the electric on its own road, and the steam train on the west-bound express track. Both trains started together, but the steam engine got away quicker. This was due to an abnormal drop in the voltage of the current, which fell to as low as 375, instead of 600 volts. The result was that up to 3,000 feet from the starting point the steam train was gathering speed faster than its rival, but at this distance the pace of the electric train attained that of the steam locomotive. From this point the electric train accelerated more rapidly. It crept up, drew level with the steam train, and forged ahead at the second milepost. The driver of the steam locomotive let his engine go for all it was worth, and notched a maximum speed of 50 miles an hour, but he could not overhaul his competitor, which, travelling at a maximum speed of 57 miles an hour, drew farther and farther away, until when the power was shut off it was leading by two train lengths—practically 1,000 feet.

Second Point Gained.

Another run was made under similar conditions, and the results were virtually the same. The electric train, though slower in acceleration, owing to the drop in the voltage, caught the steam train and drew clear before the current was shut off. On this test higher speeds were attained b both trains, the steam locomotive reachin 53·6 miles, while the electric train toppe 60 miles, per hour.

The Thir Triumph.

For the third run the trains were reduce to six coaches, bringing the weight of th steam train down to 427 tons, and that of the electric train to 407½ tons. Here again the steam train got away more quickly, bu in this case the voltage dropped as low a 330 volts. The result was that during th first half-mile the steam train held the uppe hand in acceleration. Once it got into it stride, however, the electric train com menced to make up leeway, and at th end of the first mile drew ahead, and racing at 61·6 miles per hour, continue to gain until the power was shut off.

Another run with these trains was com pleted, only in this instance, in order t secure still closer relative results, and t bring the electric train more analogou with the conditions which would prevai in the electrified zone around New York the start was made from the second mile post. By this means a higher voltage wa obtained, owing to the start being mad nearer the sub-station. The two train started level, but owing to the higher voltag the electric train commenced to accelerat from the first revolution of its drivers, s that it led from the start, and after coverin 1,500 feet was a full train length ahead.

These tests were followed with intens interest by the officials for whose benef they were conducted. Two heavy train drawn by powerful monsters racing neck and-neck over a short length of railwa afforded a novel and thrilling spectacl Each type of locomotive represented th latest development in its particular field and was the most powerful and fleetest of it class. The driver of the steam locomotive being unfettered and keen upon demonstrat ing the pace of his engine, entered int the race with the utmost zest, and it wa admitted that the steam locomotive, unde

its skilled crew, gave an excellent account of itself.

Upon the conclusion of the foregoing tests two runs were made by the electric locomotive in order to ascertain its speed powers. In the first sprint only one coach was attached, with which a maximum speed of 79 miles per hour was registered. In the next effort the locomotive was run light, and with the current shut off on curves. Despite the latter handicap the locomotive recorded 80·2 miles per hour. This run was decidedly impressive, and had it not been for the restriction on the curves, it is believed that 90 miles an hour would have been put up. As it was, the above performance was excelled two days later, when the engine in a speed burst attained a velocity of 85 miles per hour, with speed reduced to 78 miles per hour when rounding the sharpest curve.

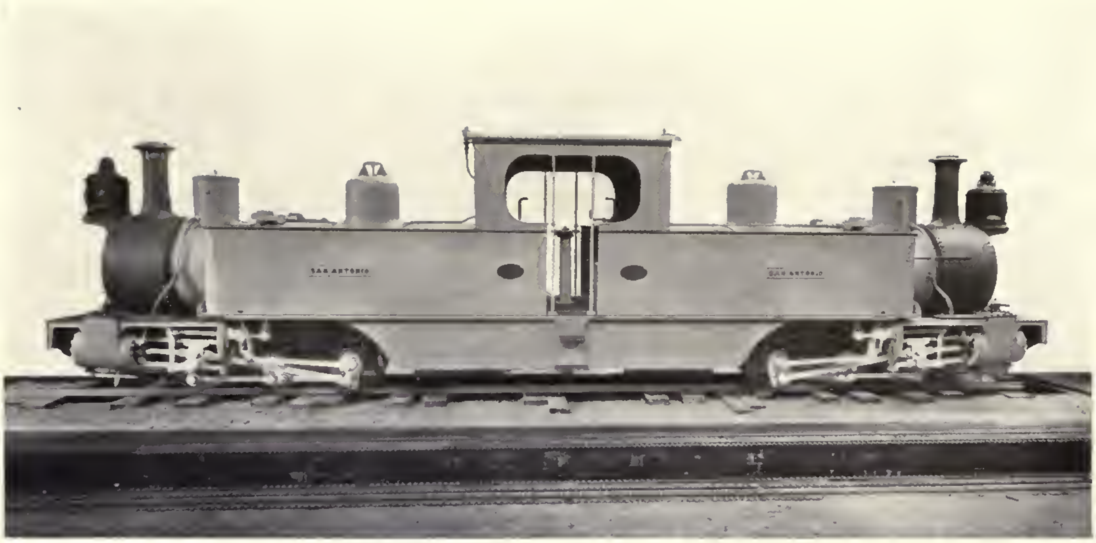
These tests emphasised the overwhelming superiority of the electric locomotive. Whereas the steam train starting from rest required 203 seconds to accelerate to a speed of 50 miles an hour, its electric rival notched the same speed in 127 seconds. Then, again, the paying load behind the electric locomotive was 76 tons greater than that behind the steam locomotive, all other things being equal.

The officials of the New York Central Railroad were convinced of the possibilities of this form of traction upon the electrified sections of their system, and they entertained no apprehensions concerning the wisdom of their policy.

Subsequent experience has fulfilled their anticipations completely; their enterprise reaped its due reward. To-day the electrical working of main line express traffic is not regarded with any apprehensions. The heavy initial outlay that has to be incurred is the sole hindrance to the transformation.

Photograph by permission of the British Thomson-Houston Co., Ltd.

THE ELECTRIC LOCOMOTIVE AFTER ITS CONTEST WITH THE SNOWDRIFTS.



THE "FAIRLIE" LOCOMOTIVE USED ON THE BOLIVIAN NARROW GAUGE RAILWAYS.

The "Fairlie" Double-ended Locomotive

A DESIGN OF ENGINE EVOLVED TO OPERATE ON SHARP CURVES AND STIFF GRADIENTS

FROM time to time ingenious efforts have been made to depart from what may be described as the orthodox in locomotive design. Such ingenuity has been prompted by the desire to obtain an engine which will meet peculiar prevailing conditions more efficiently than the familiar type of locomotive.

This quest is by no means of recent date. The necessity of some such development was realised in the days when railways were young. The engineers of motive power found it difficult to secure economical working upon the roads with their sharp curves and heavy banks laid by the early railway builders. The fact that the cheapest and easiest extrication from the quandary was to rebuild the lines was not recognisec at that time; or, if it was, the treasurie were not sufficiently rich to sanction costly reconstruction. Accordingly the mechanica engineer was compelled to make the mos of a bad bargain, and this situation stimu lated his ingenuity to a marked degree.

The countries which were the greates offenders in this respect were those o recent exploitation, or which were only beginning to attract commercial interests such as Australasia and the South Americar States. There the railway builders, hamp ered by scarcity of funds, reduced the cos of construction to the lowest possible level carrying their tracks over obstacles witl long stretches of banks running up to 1 in 25, and writhing and twisting throug favourable channels intersecting the moun

tains in an amazing manner, so that curves of 250 feet radius were more the rule than the exception. The builders scarcely gave a thought to the railway operator.

As the years rolled by, and the traffic over these lines became heavier, it grew more and more difficult to adapt the ordinary type of locomotive to the work with any pronounced degree of cheap working. In the attempt to surmount the difficulty many freakish designs were devised, but, needless to say, they only enjoyed a fleeting existence. They were ingenious, it is true, but being more novel than practical, they only helped to swell the inventor's scrap-heap of hope.

Among these tireless experimenters was a Scottish engineer, Robert Francis Fairlie.

In 1864 he introduced his solution of the problem, and the unusual design aroused considerable interest. It resembled two tank engines placed back to back with a common cab and boiler. Each moiety appeared to be complete, with its smoke-stack and driving wheels placed beneath the fore part of each boiler. The most conspicuous feature of the locomotive, however, was that each driving wheel unit, together with its cylinders, was carried upon a bogie truck. By this means flexibility was secured, since the upper part of the engine, comprising the boiler and fire-box, was pivoted at either end upon the bogie. This arrangement enabled increased adhesion to the rails to be obtained, as well as a more efficient distribution of

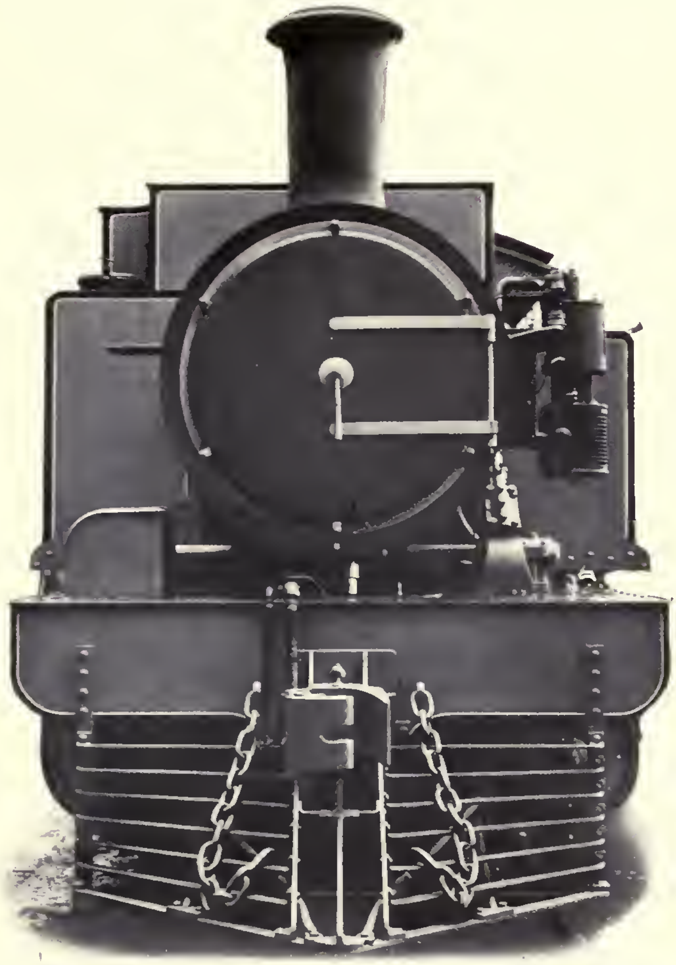
THE DOUBLE BOILER, FIRE-BOXES, AND FOUNDATION RING OF THE LARGE "FAIRLIE" ENGINE BUILT FOR THE MEXICAN RAILWAY.

He passed through the stern school of practical railway experience both in Ireland and India, finally relinquishing active operations in favour of a consulting engineering practice in London. He attacked the problem, and his varied railway knowledge and the peculiar conditions governing the question gave him an advantage over his contemporaries, many of whom were amateur railway enthusiasts, possessed of merely a rudimentary knowledge of the subject or what was required.

weight upon the axles, while at the same time the sharpest curves could be negotiated with ease. The engine, being double-ended, could be driven in either direction, so that turning round was obviated. The cab was placed centrally, only on each side of the boilers.

Despite its unusual appearance, the engine substantiated the claims of its inventor, and was adopted promptly in those hilly countries where curves and grades were adverse to the ordinary locomotive. It was

introduced into New South Wales, New Zealand, the South American countries, Russia, Sweden—in fact, in all those districts where it offered a solution of a perplexing difficulty in railway operation.



END VIEW OF THE MEXICAN RAILWAY'S HEAVY "FAIRLIE" ENGINE.

The system, of course, possessed disadvantages. The mechanism was somewhat more complicated; trouble was experienced in keeping the expansion and ball and socket joints, conveying the steam from the boiler to the cylinders and from the latter to the exhaust, tight; while in later models, of larger size, the variation of the water level in the boilers when the engine was working over steep banks was considerable. Many ingenious attempts to eliminate these shortcomings were made, but they only succeeded in emphasising t complications. Three engines of this cla which were built some years ago by American firm for service in Central Americ were among the most complicated railw engines which ever ha run over the steel hig way.

Taken all round, ho ever, the Fairlie engine m the peculiar situation a purposes for which it h been designed very effe ively. Now it may be se working in all parts of t world where the count threaded is mountainou and where inclines are ste and curves are sharp. U to the present no oth type of engine has prov more suited to the wor and as a result larg and more powerful Fair engines have been built meet exigencies of traf over the lines upon whi they were introduced. fact, in certain instances, far, it has been the mea of avoiding the cost process of re-aligning a reconstructing the pione roads.

The Mexican Railwa has three of these engine which are among the most powerf and largest of their character th ever have been constructed. They we built at the Newton-le-Willows loc motive works of the Vulcan Foundr Limited, to handle trains of 300 to over banks rising 1 in 25, with curv of 325 feet radius. This standar gauge railway possesses some of t stiffest stretches of road worked b adhesion that it is possible to find Central America.

A HEAVY POWERFUL "FAIRLIE" LOCOMOTIVE, BUILT FOR THE MEXICAN RAILWAY.

It weighs 138 tons. The photograph shows the disposition of the driving wheels on two bogies and the driver's position on the footplate. Comparison with the man conveys an impressive idea of its large proportions.

The Boilers.

The two boilers, each measuring 12 feet 11 inches in length by 5 feet outside diameter, and containing 216 steel tubes, are in one piece, though there are two separate fire-boxes, with water space between. A steam dome is placed upon one barrel, and provided with four "pop" safety valves. The total heating surface of the boilers is 2,924 square feet; the grate area is 47·75 square feet. A conspicuous feature is the large foundation ring for the two fire-boxes, which is made in one piece out of the solid and without weld.

Steam Pressure 185 pounds to square inch.

Each bogie truck carries three pairs of driving wheels, 4 feet in diameter, the wheel base of the bogie being 9 feet 3 inches, while the total wheel base is 35 feet 6 inches. The four cylinders — two on each bogie—have a diameter of 19 inches and a stroke of 25 inches. Steam is used at a pressure of 185 pounds per square inch. The over-all length of the locomotive is 56 feet $1\frac{3}{4}$ inches, while the total weight in running order is 138 tons—69 tons to each engine. The whole of this weight, representing 23 tons per axle, is available for adhesion.

Reversing Gear.

The valve-gear is of the Walschaert pattern, and the reversing gear has been designed specially to prevent the position of the valve motion being affected by the engine when entering or leaving curves. The reversing wheel is operated by means of bevel gears, which move a horizontal shaft fixed on each bogie, together with a quadrant and worm gearing. There is a ball and socket joint at both ends to ensure flexibility, and a slot and sleeve on the diagonal shaft allows for the bogie's movement. The motion is locked by means of an air cylinder operated by the Westinghouse air-brake apparatus.

Either coal or oil fuel may be used. The regulator and driving control are placed on the footplate on one side the fire-boxes, which extend through t centre of the cab, while firing is carried o from the opposite side. The arrangeme certainly makes the cab somewhat confine but in this case this drawback is n experienced to the same degree as in Fairlie locomotive built for narrow gau lines. Either engine may be used i dependently of the other, two regulat handles, mounted one above the other a working horizontally in a toothed quadrai being placed on top of the boiler for t driver.

These engines have proved highly su cessful in Mexico and are performing e cellent work. They are engaged in hauli trains weighing 340 tons over the stiffe banks and the sharpest curves, at a spe of 9 miles per hour.

On the Boliviai Railway

Another engine of this type, thou differing in certain conspicuous featur which emanated from the Sheffield works of the Yorkshire Engine Company, Limited, is working upon the 2 feet 6 inches gauge lines of the Bolivian Ra ways. Here the grade runs up to 1 in while the curves are as sharp as 230 f radius. These engines not only had to capable of handling heavy loads over su difficult portions of the system, but h to be capable of completing long runs well.

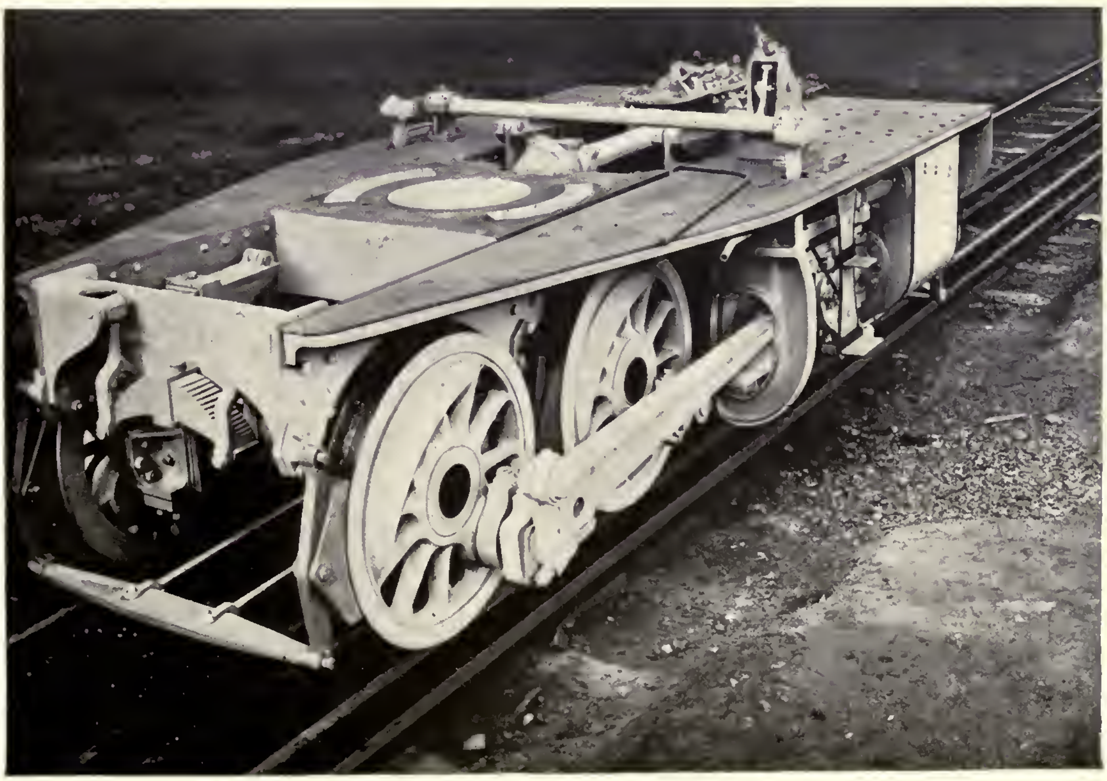
In this instance, instead of there bei one double boiler, there are two separa boilers of the Belpaire pattern. Tl arrangement not only reduces the troul experienced in connection with the var tions of the water level within the boile owing to the inclination of the engi but provides a roomier cab similar to tl of the ordinary engine. The water tan capable of carrying 1,500 gallons of wat are continued under the platform of t cab. The motor bogies, each with coupled wheels of 2 feet 6 inches diamet have a rigid base of only 6 feet, the to

wheel base being 29 feet $4\frac{1}{2}$ inches. The centre pair of wheels on each bogie is flangeless, and each bogie carries two outside cylinders, having a diameter of $12\frac{1}{2}$ inches by 16 inches stroke.

Owing to the narrowness of the gauge the centre of gravity is kept very low, the centre line of the boiler being only 4 feet $10\frac{1}{2}$ inches above rail level. The boiler measures 9 feet $3\frac{3}{4}$ inches in length by 3 feet $5\frac{1}{8}$ inches diameter, and contains 106 tubes, the total heating surface being 1,046·88 square feet, and the grate area 21·66 square feet.

In this engine the reversing shaft is carried along the tops of the tanks, the gears being coupled and operated with a screw and wheel action carried on a pillar in the centre of the footplate. The steam distribution also is carried out upon improved lines, with the object of overcoming the difficulty in keeping the pipes and joints steam-tight, which was one of the great objections to the earliest types of Fairlie locomotive. The sand boxes are placed on top of the boilers, just behind the smoke stacks, and the sand is led to the wheels of the bogies through flexible pipes. Each engine can be driven independently of the other, a regulator handle of the general pattern being placed in the usual position in each part of the cab. The total weight of the engine in running order is 52·1 tons.

Although many efforts have been made to devise an engine superior to the Fairlie for the service in which this locomotive excels the broad principles laid down by the Scottish engineer half-a-century ago still appear to reign supreme. Modifications have been made in regard to the general details, but the fundamental principles have undergone scarcely any improvement.

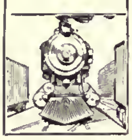


ONE MOTOR BOGIE OF THE "FAIRLIE" ENGINE USED ON THE MEXICAN RAILWAY.

AN EARLY LOCOMOTIVE AND ROLLING STOCK, SHOWING CHEAP TIMBER TRESTLE CONSTRUCTION.

From Failure to Fortune—The Stor of a Great Transcontinental Railwa

HOW THE NORTHERN PACIFIC, HANDICAPPED BY GREAT FINANCIAL CRISES, WON THROUGH AND JUSTIFIED THE FORESIGHTEDNESS OF ITS PROMOTERS



AT the dawn of the nineteenth century the settlement of the United States was confined to the belt lying between the Atlantic and the Alleghany Mountains. Between the Mississippi River and the Sierra Nevadas was that vast tract of 883,072 square miles which, in 1803, was sold by Napoleon to the United States for £3,000,000—a transaction handed down in history as " the Louisiana purchase."

Directly this vast territory came under the Stars and Stripes a keen anxiety to explore its innermost parts became manifest. Many expeditions were organised, but only one matured—that of Lewis and Clark. These intrepid spirits, after experiencing privations and adventures innumerable, gained the Pacific seaboard. The discussion of their journey revealed the fact th an overland channel of communicati between the Atlantic and the Pacific Ocea could be provided. Accordingly a numb of schemes—many of the wild-cat order- to this end were formulated.

The most popular project was to follo the two great rivers, the Missouri and t Columbia, to their respective headwate on the eastern and western slopes of t Rocky Mountains, which, it was point out, would need only a short length intervening rugged country to be bridge Every traveller who succeeded in crossi the country by pack-horse, Indian dug-o and shanks's pony waxed loquacious abo the ease and simplicity (!) with which railway could be built through the mou tain barrier.

However, the scheme languished un

1844, when it was taken up in grim earnest by Asa Whitney. He was a man of wealth, and he devoted all his energies and resources to arousing public interest for the construction of a northern transcontinental railway. He was assailed on all sides by hostile criticism, but he fought tenaciously until, having frittered his whole fortune away in propaganda, he retired from the scene to eke out a humble existence as a milkman for the remainder of his days.

The Pacific Railway Surveys.

But Whitney's work had not been in vain. He had infused others with his enthusiasm, and among these was Edwin F. Johnson, of Vermont, who, being a clever engineer, with a big reputation, was fitted to the task. He was very aggressive, and although he did not escape criticism, extreme care had to be displayed by detractors in attacking his proposal, inasmuch as he tore technical objections raised by laymen to shreds. Johnson hammered away at the project until at last he forced the Government to sanction that momentous enterprise, the Pacific Railway Surveys, which was carried out by the foremost topographical and military engineers of the time. Five expeditions were dispatched to the coast, each being allotted a section of the mountains which it was commanded to probe through and through, to find the easiest route for a railway. These labours are summarised in thirteen bulky volumes, which have an honourable and undisturbed resting place in the archives of the Government. They are fine pieces of work so far as they go, but the railway builder of to-day regards them with ill-disguised disdain; he prefers to work out his own salvation.

When these reports were submitted to the Government in 1855 they aroused widespread interest, and formed a perennial topic of idle parliamentary debate for another six years. But in 1862 matters came to a crisis; academic discussion was brought to a dramatic end. The State of California demanded railway communication with the Eastern States; if this request were not met, it would secede from the Union. Faced with the possibility of disruption, Congress was stirred to action, and sanctioned the building of the Union and Central Pacific Railways, to constitute the first transcontinental steel highway across the country.

The Northern Pacific Scheme Sanctioned.

But this decision was at the expense of the cause which Whitney and Johnson had espoused so valiantly, and, as may be supposed, the Government decision inflamed these interests. Johnson became uncompromisingly aggressive, and, as he had a large and influential following, the position of the Government became somewhat perilous. Finally, to appease the advocates of the northern route, and to satisfy public opinion, the construction of the Northern Pacific *Railroad* was sanctioned, the Act being signed by President Lincoln on July 2nd, 1864.

The fathers of this enterprise were jubilant. They had won the day, and completed preparations to "make the dirt fly." Johnson was given the reins of the undertaking, and under his banner was enrolled a corps of the finest engineers in the country. The surveys were run and the location decided; everything was ready to start. But there arose one insuperable obstacle: whence was the money coming to finance construction?

The Civil War Interferes.

Then came the Civil War. The railway project was blown sky-high by that great upheaval. Money could not be obtained under any conditions; the financiers clutched their hoards and refused to provide a penny. But every contretemps brings its own solution. The Government, being in a similar plight, was forced to appeal to the people, and in this movement a new financial force was introduced—the hitherto obscure banking house of Jay Cooke and Company, of Philadelphia. Owing to the

remarkable success of this firm in the sale of Government securities to the tune of £266,000,000 during the dark days of the war, the Northern Pacific Railroad urged this house to help them in the provision of funds for construction in a similar manner. The bank dispatched its independent engineers through the west to investigate. The reports being satisfactory, the house agreed to appeal to the people, as in the case of the Government's dilemma. It entered into the undertaking with enthusiasm, and embarked upon an elaborate campaign to make known the agricultural, industrial, and commercial possibilities of the country traversed by the Northern Pacific.

This in itself was a stupendous piece of work. In 1870 the territory which was to be penetrated by the new transcontinental boasted only 600,000 people, of which the State of Minnesota alone claimed 400,000. The remaining 200,000 were divided into small communities scattered here and there over territory which was the home of the Indian, the buffalo and other animals. Montana did not possess a sheep or a cow; North Dakota was a silent wilderness; Eastern Oregon and Washington were the haunts of the bear and trapper. In view of such conditions it is not surprising that timidity was displayed by investors; that Jay Cooke's attractive statements were regarded with suspicion; and that carping critics wanted to know whence the railway was to derive its traffic.

An Uninhabited Route.

Yet the financiers and railway forces were not dismayed. With the money which was harvested 2,000 navvies were set to work in 1870 with their shovels, picks and wheelbarrows at a point twenty miles west of Duluth, Minnesota, their eyes being turned towards the Pacific. The metals were brought up from the mills and discharged at Duluth at £18 per ton, from which point they had to be hauled to the grade as circumstances permitted. By th end of the year the winding ribbon of ste had been laid to the banks of the Red Riv in Minnesota. Simultaneously the forc toiling on the western arm, which was advance eastwards from the Pacific, ha been busy, the first sod having been turn on the banks of the Columbia River ne Portland.

The Work Begins.

Once started, work went ahead, althoug money was tight. Congress was asked assist, and in 1871 consented to the company mortgaging its road and land grant. The plains were traversed as far as Bismarck on th Missouri River, while the line had bee carried from Portland to Tacoma, wh came the great financial crash of 187 It caught the young railway at a di advantage. The statements which Ja Cooke and Company had circulated co cerning the possibilities of the countr penetrated were assailed vigorously. S called independent investigators on the sp were commissioned by parties of investo to make a trip over the completed portio of the road and to report upon the outloo These wiseacres were prejudiced in th first instance, and, accordingly, when th trains drew away from civilisation an rattled through a silent country reflecti nothing but a drab, sun-scorched surfac as uninviting as the Sahara, the spirits the so-called experts sank lower and lowe They did not look a few inches below th exposed surface; knew nothing about th constituents of the soil; were ignorant farming.

The Cra of 1873.

"Sell! Sell! Sell!" This was th advice the investigators wired back their investing friends in the cities. At that time there were 13,000 stockholders in the company, and no astute manipulation wa required to precipitate a panic amon them. The stock was thrown pell-me on the market to be sold at any pric Members of the directorate, who cherishe

Disaste

FILLING IN A TRESTLE BY HYDRAULIC SLUICING.

Building an embankment with material washed down from the mountain-side by water jets. This method has been borrowed from the old placer miners.

THE NORTH COAST "LIMITED" LEAVING ST. PAUL.
Drawn by the latest type of Pacific (4-6-2) engine.

THE NORTH COAST "LIMITED," REAR VIEW, SHOWING THE OBSERVATION CAR.

unbounded faith in the undertaking, endeavoured to stem the disastrous tide by bringing tracts of 3,000, 5,000, and 6,000 acres fringing the railway under cultivation, just to show what the ground would yield. But their puny efforts were in vain. The news had gone forth that the Northern Pacific was traversing a desert, where life was impossible, and where not a blade of grass could grow. The stampede could not be stayed; when the public loses its head judgment flies out of the window. Jay Cooke and Company strove hard to turn the panic, but unsuccessfully, and they went down in the debacle.

THE NORTHERN PACIFIC TRANSCONTINENTAL EXPRESS CLIMBING THE 116 FEET PER MILE GRADE THROUGH THE ROCKIES WITH A "DOUBLE-HEADER."

When the train is heavy a third engine is attached as a "pusher."

Construction was brought to a standstill. Not another penny could be raised. The adverse reports which had been circulated were too damning to release the purse-strings. The directors hung on, hoping against hope that the situation would right itself, but the corner could not be turned. The line went into bankruptcy. This was a heartbreaking shock to those who had fathered the scheme. They had built 555 miles of line, owned 48 locomotives and 1,230 freight vehicles—not a bad return for five years' work. Yet far more convincing than the mileage of steel highway and the rolling stock was the solidity of the foundation of the Middle West which had been laid. In 1870 not a single bushel of grain had been taken off the land which the railway threaded; in 1875 over 500,000 bushels were harvested in this so-called desert!

After the smash a stand-at-ease policy was maintained for some years to enable the United States to recover its financial footing. The line was kept in thorough repair, and showed a steady increase in its revenue, while the desert land, regarded with disdain, attracted scores of settlers who brought it under cultivation.

There was one popular fallacy which held the country locked firmly against agricul-

tural expansion. This was the impression of the prairie winter, which was said to be a nightmare. Certainly the icy blasts from the North have a clean sweep of several hundred miles over country as level as a table-top; the snowfall is heavy, and, being unobstructed in its helter-skelter drift, it does pile up in huge banks, 40 feet or more in depth—even to this day. The soldiers who were striving to subdue the recalcitrant Indians holding the Middle West drew fearsome pictures of the blizzards, the blood-freezing low temperatures, and the long, hard winter. These highly-coloured reports even scared the settlers who ventured into this domain to such a degree that many, after they had gathered their harvests, locked the doors of their shacks, departed to the towns to hibernate through the winter, and returned to their lands in the spring.

The Winter Traffic.

Unfortunately the railway management made no effort to dispel these fears; rather they supported them. When the last bushel of grain had been loaded into the railway truck and dispatched to market, all locomotives, wagons, and men on the prairie were withdrawn. The company concluded that it was better to close down the railway for five months or so rather than face the fury of winter.

These illusions prevailed until they were dispelled in a somewhat unusual manner. The Sioux Rebellion of 1876, the massacre of Custer and his little band, and the general insecurity of the country arising from the success of the Red Men stung the Government to drastic action. The railway had reached the east bank of the Mississippi, and Bismarck, at the railhead, had become an important strategical centre. The Government completed its plan of campaign; Bismarck was to be the base. As it was essential for the War Office to be in close rail and telegraphic communication with the front, the railway company, after the harvest of 1876 had been garnered, was asked to refrain from withdrawing its men and rolling stock for the winter, but to keep the line open for military purposes.

The Government traffic was somewhat heavy, and Nature, as if determined to aid the refractory Red Men, hurled its forces—blinding blizzards, tornado-like winter storms, and heavy snowfalls—upon the railway with unparalleled savagery. Yet the management experienced no difficulty in keeping the line open. The delays to the trains were slight and the rolling stock suffered no injury. Assuredly the terrors of the prairie winter had been exaggerated. Why, the Northern Pacific suffered fewer losses and less delays from the snow-fiend on the open plains than had the New York Central in the settled East during the same winter! The bogey was laid; from that winter forward the line was kept open the whole year round.

Bridging the Mississippi.

In 1879, the railway having retrieved its position somewhat, financial aid was forthcoming, and construction was resumed. On the eastern section the broad rolling swathe of water of the Mississippi River had to be crossed. This demanded a massive metal bridge, 1,400 feet long, divided into three spans, with the railway track placed 50 feet above the water. By the time this was completed £200,000 had gone—a somewhat big item, when money was tight, to advance the railway by less than a quarter of a mile! After the west bank was reached the constructional forces advanced over the rolling plains of Dakota and Montana as far as the foothills of the Rockies at a rapid pace. The surveyors eased the cost of construct on by following the line of least resistance. Instead of conquering prodigious obstacles by the completion of striking pieces of work, they sought to avoid them, although the grade and curvature suffered somewhat in the process.

On the west coast the railway was pushed forward just as rapidly, although there.

owing to the Cascades disputing advance, progress was less marked in point of distance. Huge rifts in the mountains had to be spanned, and these were overcome stern resistance, so that several months passed before the Bozeman Tunnel, 3,610 feet long, and the Mullan Tunnel, of 3,847 feet, were pierced. Simultaneously with the

THE NORTH COAST "LIMITED" CROSSING THE BRIDGE SPANNING THE MISSISSIPPI RIVER, WHICH DIVIDES THE TWIN CITIES OF ST. PAUL AND MINNEAPOLIS.

by erecting massive timber trestles, for which millions of feet of lumber cut in the vicinity were used. The humps of the mountains were trimmed back to provide a narrow causeway for the metals. The turbulent mountain rivers were spanned by heavy wooden bridges and trestles, everything being carried out upon pioneer lines to reduce constructional costs as much as possible.

While tunnelling was reduced to the minimum, it could not be avoided entirely. Two heavy works of this character were required to get through the Rocky Mountains. In both cases the rock put up a

driving of the main line from each end, short spurs were laid down into promising districts for mining, lumbering, and agricultural development. In nearly every instance the branches resembled the main track, inasmuch as they preceded the settlers, so that a period of some years of unproductiveness had to be faced before any profits were likely to accrue.

The vigorous energy with which construction was maintained when the engineering forces once more settled down to their stride was due to the tireless activity of Mr. Henry Villard, who assumed control of the railway, and who, having built up

a commanding railway managing reputation in the West, was fitted to the post, which, under the stringent monetary conditions, was somewhat onerous. Villard was a born railway administrator, of strong character and remarkable foresight, who commanded the unbounded confidence of powerful financial interests. He had been associated with Mr. Thomas Alva Edison, and, in 1881, when the Wizard of Orange was experimenting with his electric railway at Menlo Park, for the construction of which Villard was primarily responsible, and in which he sank his own money, he discussed with Edison the electrification of the Northern Pacific through the Rocky Mountains. When it is remembered that at this date electric railway working was in its infancy, when not more than 2½ miles of electric railway were in operation, and that as an experiment, the idea of applying this motive power to a section of a transcontinental railway was somewhat daring. But Villard maintained that electric operation would be cheaper than steam, and that it was certain to be used for the mountain sections of big railways at all events, since adequate energy is generally available from the mountain torrents.

THE OLD AND THE NEW, NEAR LAPPINGTON.
To the left is the original bridge built of wood. The old line was abandoned when the new, straight and more level track was finished.

Villard also trusted his engineers implicitly—he did not hamper them in any way. It was up to the engineers to give the best return on the outlay. The engineers appreciated this feeling of trust, and certainly gave the President as fine a railway as could be expected, though in consummating this end they spent some £4,000,000 more than was anticipated. Villard spurred his men on, since he recognised that the sooner the undertaking was completed the earlier would a great stream of traffic flow along the steel channel. The

spring of 1883 saw the two long arms within measurable distance of one another, and it was only a matter of weeks before the rails from the east met those coming from the west. On September 8th, 1883, amid wild festivity, the golden spike was driven at Gold Creek, in Hellgate Canyon, Montana, the spike used for the auspicious event being the very first that was driven into a sleeper 20 miles west of Duluth in 1870, when the Northern Pacific Railroad was commenced. By this linking together of the two sections an aggregate of 2,259 miles were brought into operation.

The most sensational display of engineering on the whole line, however, was the driving of the Stampede Tunnel, to overcome the Cascade Mountains. The route across this obstacle had been a matter of discussion among the officers of the company since the first spadeful of earth was turned in 1870, and for eleven years the question was debated as to which pass through the range should be followed. The surveying engineers narrowed the issue down to a choice of three—the Natches, the Stampede, and the Snoqualmie Passes. Whichever route was taken a tunnel was necessary, so that it was a matter of selecting the most advantageous route from the economic and traffic point of view.

The Stampede Tunnel.

The decision was left almost completely to Mr. Virgil G. Bogue, who at that time was chief assistant engineer. He had been spying through the mountains for years, being responsible for the mountain division of the railway. Through his energy the Stampede Pass was discovered, he having sent a party through the mountains over this route, when no knowledge of such a gateway existed. Mr. Virgil G. Bogue is one of those great railway engineers who have been created by railway building in the western United States, who at a later date provided the United States with its easiest and fastest transcontinental railway—the Western Pacific having a maximum grade of only 52 feet per mile—as described in another chapter.

In 1884 Mr. Bogue recommended the adoption of the Stampede Pass, and outlined a tunnel nearly 2 miles in length, which he estimated could be completed in twenty-eight months. Acting on this advice the railway company called for tenders for the contract. There was no intention of permitting the successful contractor to dally over his work. The bore was to be completed in the above time under a penalty of £20,000 and 10 per cent. of the contract price. All the leading railway builders on the continent bid for the work, but when the tenders were opened it was found that an unknown man, Nelson Bennett, was ready to accept the conditions, and to complete the job for £232,000. His nearest rival wanted over £400,000. The Bennett tender was accepted, but the competing firms maintained that it never could be done for the price, and that the contractor from the west would "go broke" over the transaction. But Bennett knew more than they. He had built some of the most difficult sections of the line in the western mountains; had worked under Mr. Bogue; and was confident that the time set down was adequate for the task, so was prepared to rely on the estimated time.

The contractor hustled. His bid was accepted on January 21st, 1886, and he had undertaken to complete the tunnel by May 21st, 1888. Leaving the Northern Pacific Railroad offices in New York with his contract, he at once ordered all the plant required, at the same time wiring to his general manager in the west to gather an army of men and to cut roads from the railheads to the tunnel site. What this meant may be gathered from the fact that a wagon-road had to be driven through primeval mountain forest for 82 miles on the east, and for 87 miles on the west side of the range, rising from 500 to 4,200 feet altitude. The

The Contractor's Difficulties.

cutting of these tôte-roads, and the transport of the heavy machinery was far more exacting and difficult than the boring of the tunnel itself. The country was under snow at the time, and huge sleds were improvised from trees cut down on the spot. There came a sudden thaw, and the surface of the rude road was converted into mire about 4 feet deep. The heavy loads had to be hauled through this semi-liquid glue by block and tackle, and a mile a day was a good average progress.

An advance army of men were got on to the tunnel site with as much speed as possible, and they commenced driving the bore $16\frac{1}{2}$ feet wide by 22 feet high through the detritus on each side. In this preliminary work two mountain streams had to be diverted, one of which fell in a beautiful cascade across the eastern portal from a height of 170 feet.

While the tunnel faces were being excavated the railway engineers appeared on the scene to lay a temporary track over the range. This in itself was an amazing piece of work, comprising a switchback along which the trains were pushed and pulled from level to level over grades running 300 feet per mile. Standing at the top of the western zig-zag six tracks were revealed sawing to and fro down the slope. This switchback cost £80,000 to build, and was completed by July 2, 1887. When it was abandoned ten months later, upon the completion of the tunnel, the switchback had earned £100,000 for the company, so that, although £80,000 worth of work was scrapped, the company had profited by £20,000 over its provision.

An £80,000 Switchback.

Owing to the difficulties encountered in reaching the portals six out of the twenty-eight months allotted to the task slipped by, together with an expenditure of £25,000 in getting up the machinery. By this time the advance gangs of men had driven their way into the mountain, from each side, for a total distance of 900 feet with hand-drills, leaving 8,950 feet to be drilled through rock by the machine tools in twenty-two months. The men were divided into ten-hour shifts, at wages ranging from 10s. to 20s. a day, according to their skill, and as much more as they could make over the 13·58 feet per day which was set down as the average progress necessary to complete the tunnel on time.

Drilling the Bore.

No effort was spared to maintain the scheduled rate of advance. But when water burst in, and caused the rock-hogs to abandon their task, serious delays occurred, so that the work completed fell behind the required amount. Then friction arose between the contractor's superintendent, who was popular with the men, and the railway company's resident engineer. At last the tunnel builder was forced to request the railway to change their official, as the contract was in jeopardy. This was done, and, harmony being restored, the miners set to work with redoubled energy. They not only made up leeway, but got ahead of the schedule. As the borers knew that the contractor was up against a time-limit they let themselves go. Spirited rivalry sprang up between the gangs working on the two faces as to which finally would put the greatest length of the tunnel to its credit.

The bore was driven from a centre heading, from which it was widened out subsequently to its full dimensions. An ingenious machine was devised to facilitate work at the heading. It was like a big table, straddling the full width of the tunnel, with its legs mounted on two-wheeled trucks which ran along a track. It was sufficiently high to permit the dump cars to pass beneath, to be filled from the top of the table through shoots. The "bench" or footing of rock in the lower part of the tunnel was kept 30 feet from the drilling face in the heading, and on this the drillers toiled. When the holes had been driven, and the "shots"

An Ingenious Machine.

REBUILDING IN STEEL THE OLD TIMBER TRESTLE ACROSS GREENHORN GULCH IN THE ROCKY MOUNTAINS.

Lowering a 61 foot girder from the cars.

tamped home, all tools were thrown upon this travelling table, which was pushed down the tunnel for some distance while the blast was made. When the smoke and fumes had cleared away the table was pushed to the front again, a fresh series of holes driven in the rock face, the muck brought down from the previous shots being cleared on to the table and emptied through the shoots into the trucks beneath. The men appreciated this device, and promptly dubbed it the "Go-Devil."

As the time-limit drew nearer and nearer money was poured out like water to keep pace with the scheduled advance. The spirited urging of the contractor was not in vain. The men became infused with his zeal, and they drew heavy rewards in bonuses. The labourers were fed well at the contractor's camps at a cost of 3s. a day, while the only other essential expenditure was a contribution of 4s. a month towards the hospital established for their benefit.

On May 3rd, 1888, eighteen days before the expiration of the contract time, the last piece of rock was broken down, permitting the opposing drilling forces to shake hands with one another. Eleven days later the excavation was completed. Two days after the metals were laid from end to end, and on May 21st, the contracted date, Bennett handed over the work to the railway, the first regular train running through the bore on May 22nd. As a tunnel-boring achievement, bearing in mind the abnormal difficulties encountered in getting to the work, it stands unique.

When the completed line settled down an era of prosperity appeared to be

assured. Settlers were pouring into the country, and were developing the land contiguous to the main line and its spurs. The rolling stock had grown in 1883–84 to 391 locomotives, 283 passenger coaches, 10,149 freight cars, while the gross earnings had risen to over £2,100,000 per annum. A policy of overhaul was immediately taken in hand, owing to the prosperity of the line and the growth of its traffic. The timber trestles were buried under solid earthen embankments piled up by washing hills of spoil down in streams from the mountain sides under hydraulic jets. Timber bridges across creeks and torrents were replaced by metal structures, and flatter banks and easier curves secured. In three years over 3,760,000 new sleepers were placed. The tracks, laid with heavier metals, were ballasted with stone gravel to permit acceleration of the cross-country expresses.

The Northern Pacific Railroad enjoyed seven years of indisputable plenty, and appeared to be established upon a firm footing. By 1899 the gross revenue had increased to £5,000,000 per annum, and the operating expenses had been reduced to 47 per cent. of the gross earnings. Unfortunately, however, owing to the exceptionally heavy cost of construction, the fixed charges became a mill-stone round its neck, the strangling effects of which were not experienced when the railway was on the crest of the wave of prosperity.

Then came a heavy fall in the traffic; the United States, with its characteristic capriciousness, was hit by another financial stampede, and the Northern Pacific Railroad was dragged down in the disaster of 1893. It was a sorry trick of fortune, but this enterprise appeared to be dogged with ill-luck. The full effect of the fixed charges

SLUICING A TRESTLE: THE LATEST METHOD OF BUILDING AN EMBANKMENT.

overload now became felt only too acutely. Villard struggled hard, but even his ability failed to stave off the crisis. A receiver was appointed to straighten things out. Villard suffered heavily. He lost his fortune and almost his reason as well. It was a disheartening sequel to years of hard work. He had snatched the railway from a moribund condition and had placed it firmly on its feet. His financial arrangements were criticised severely in certain quarters, but in an undertaking such as this, which was composed of two ends and no middle, the obvious task was to provide the missing link, even if it did entail, as in this instance, prodigious expense. When he assumed the reins the Northern Pacific was regarded as a "hoodoo" enterprise, and he had to pay dearly for the accommodation to keep the engineers going, some of the bonds and stock carrying 6 and 7 per cent. interest.

Edison and Villard.

Villard was so stupefied by the magnitude of the financial catastrophe that he would have gone under had it not been for Edison. The inventor was asked to cheer up the broken railway magnate, and only succeeded in achieving the desired end by discussing with him the electric light, which just then was coming into its own. Villard had backed Edison against all antagonistic argument concerning the electric railway, and the inventor now had an opportunity to reciprocate. He urged Villard to throw his energies into the exploitation of the electric light. The ruined financier took his friend's advice, regained his feet, and amassed a new fortune.

Revival of Prosperity.

The receivers continued the overhauling and improving policy which had been taken in hand before the crash. On September 1st, 1896, the Northern Pacific *Railroad,* valued at £65,000,000, was sold under foreclosure proceedings to the Northern Pacific *Railway* Company, and as such it is known to-day.

The third attempt to render this transcontinental highway a railway power in the land has met with conspicuous success. Now it is one of the greatest roads on the continent. The new blood, not satisfied with the condition of the property, went over it from end to end, eliminating all adverse grades and curves, strengthening bridges, re-ballasting the track, and laying it with heavier steel rails to secure still higher speeds with heavier train loads. In three years alone 829 short bridges and trestles were taken out and replaced by earthen embankments. A huge scrap-heap was perforcedly created in carrying out this policy. Larger, faster, and more powerful locomotives were introduced, while the 8 to 18-ton goods wagons were replaced by vehicles capable of carrying 20 to 45 tons.

The Land Grant.

As in the case of the Canadian Pacific, the sheet anchor of this American transcontinental railway throughout its varying fortunes has been the grant of land, which averaged so much per mile. The construction of the railway brought some 45,000,000 miles into its hands for sale, and the peopling of this vast territory not only has swelled the receipts, but virtually has ensured a traffic income, since the line handles practically the whole of the necessities and produce of this adjacent population.

Subsequent events have served to substantiate the contentions of the fathers of this transcontinental, and also the statements that were issued by the banking firm of Jay Cooke and Company respecting the possibilities of the country traversed. The land which at that time could not find purchasers at 6d. per acre now commands from £15 to £120 per acre. The tributaries of the Northern Pacific Railway ramify in all directions through the west in the interests of holiday-making, sight-seeing, agricultural, mineralogical, and forestal activity. The system has built up the prosperity of Seattle, Spokane, Portland, and a host of other cities and towns along its route.

FILLING UP A TRESTLE; THE MONITORS AT WORK WASHING DOWN THE HILLSIDE.

LOOKING THROUGH THE FORTH BRIDGE.

The Forth Bridge

A WORK WHICH COST £3,000,000 AND CONTAINS OVER 50,000 TONS OF STEEL

ALTHOUGH the majority of engineering achievements in connection with British railways which were considered brilliant wonders in their day have been since outrivalled in other parts of the world, there is one piece of work which still stands supreme. This is the Forth Bridge, spanning that storm-swept indentation on the East Scottish coast known as the Firth of Forth.

When railways commenced to grow and reached farther and farther out until at last they offered an east coast route between London and the northernmost centres of Scotland, this wide estuary offered an insurmountable obstacle to continuous communication. As is well known, this way to the North runs via Newcastle and Edinburgh to Perth, Dundee, and points beyond. Prior to the bridging of the Forth a steam ferry plied across the estuary, but this was inconvenient, slow, and uncomfortable. The result was that travellers to Dundee favoured the west coast route via Carlisle, inasmuch as thereby through direct

Photograph by A. A. Inglis, Edinburgh.

THE BIGGEST BRIDGE IN THE WORLD: THE FORTH BRIDGE, FROM NORTH QUEENSFERRY.

communication was available. An all-rail steelway was offered on the east coast, but it meant a detour of 70 miles via Stirling to reach Burntisland from Edinburgh, although the two points on opposite sides of the Forth are only about eight miles apart.

First Suggestion.

This put the east coast route at such an overwhelming disadvantage that the North British Railway Company, which was the system most vitally affected, set out to obtain direct railway communication across the estuary. The matter became imperative, owing to the acute competition of the west coast route. The urgency of some such short cut across the waterway had been appreciated years previously, and both tunnelling and bridging schemes were outlined, discussed, and abandoned as impracticable. In 1872, however, Sir (then Mr.) Thomas Bouch advanced a proposal to bridge the Forth at the old Queen's Ferry, which is so familiar to readers of Scott. He preferred this point because the Firth here is narrowed to 1½ miles, while in the centre of the estuary is the rocky islet of Inchgarvie. This engineer, who carried out the first Tay Bridge, evolved a startling proposal. His design was somewhat similar to the Clifton, Menai, Brooklyn, and other bridges of this type, with two spans, each of 1,600 feet in length.

The Tay Bridge Disaster.

The engineer succeeded in satisfying his supporters of the feasibility of such a structure, and the requisite parliamentary sanction was obtained in 1873, the Forth Bridge Company being formed, with a capital of £1,666,666, to complete the work. The contract was secured by Messrs. Arrol; but, unfortunately, several delays arose, which postponed the commencement of the task until 1879. At the time these delays were exasperating, but it was providential that they occurred. During the stormy night of Sunday, December 28th, 1879, the central part of Bouch's other great work, the Tay Bridge, fell into the Tay while a passenger train was crossing from shore to shore. Of the seventy-two people aboard not a single one escaped.

The Lesson of the Tay Bridge.

The extent of this catastrophe and the startling details which were revealed as a result of the subsequent inquiry brought public opinion antagonistic to Sir Thomas Bouch's proposal for bridging the Forth. The Tay Bridge disaster, in a way, was fortunate, as there is no doubt but that, had it been completed, the Bouch Forth Bridge would have come down with the first heavy north-easterly gale which rolled up the Firth of Forth. He had made a wind pressure allowance of 10 pounds per square foot—a ridiculously inadequate provision for such a structure as he proposed. The Board of Trade decreed that if such a bridge were undertaken it would have to be designed to withstand a wind pressure of 56 pounds per square foot on the surface of the side elevation of the structure.

A Joint Committee Investigates.

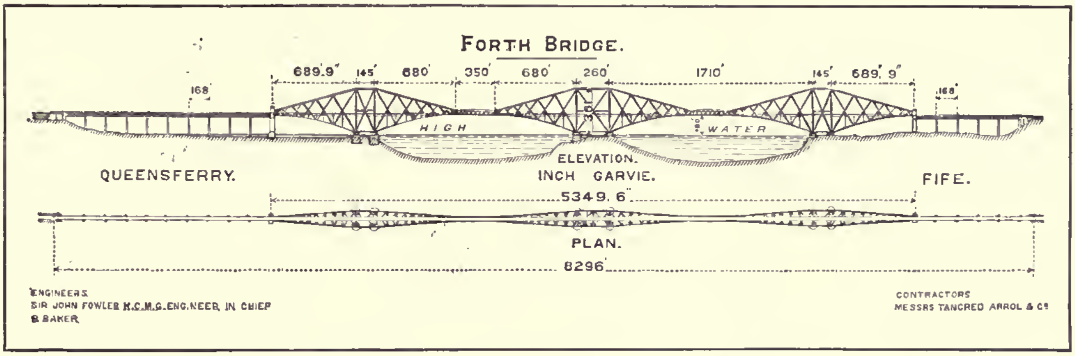
Bridging the Forth appeared to be in danger of becoming numbered among the apparently impossible things when it was revived by Mr. Matthew William Thompson, the chairman of the Midland Railway. The latter was interested in the completion of the bridge, and a meeting of the directors of the North British, North Eastern, Great Northern, and Midland Railways was held at York to consider a co-operative proposal. The engineers of the three British companies—Mr. Barlow of the Midland, Mr. Harrison of the North Eastern, and Sir John Fowler of the Great Northern—were requested to investigate the question. They did so, and, as a result, advanced the statement that the bridging of the Forth was not insuperable. Accordingly, they were invited to submit a design which they could recommend for

adoption, and which would coincide with the requirements of the Board of Trade. Sir John Fowler, in collaboration with his colleague, Mr. (afterwards Sir) Benjamin Baker, drew up a design for a massive cantilever bridge.

In spanning the Firth of Forth due regard had to be paid to the claims of navigation, which are considerable. The significance of this provision is more potent to-day, since the new British naval base, Rosyth, has been established above the bridge. Under the circumstances, a clear headway of 150 feet at high spring tides was given. The design comprised two spans each 1,710 feet in length, two of 689 feet 9 inches, and approach viaducts comprising fifteen spans of 168 feet, each resting on granite piers ; four arch spans in granite, each of 57 feet, and three of 25 feet—practically $1\frac{1}{2}$ miles in all.

The details of the design were investigated thoroughly, and finally it was adopted as being the best possible solution of the problem. Messrs. Fowler and Baker were appointed as the engineers to the undertaking. With much difficulty, and in the face of severe opposition, the requisite Parliamentary Act was obtained in 1882, and at the end of that year the contract for erection was secured by Messrs. Tancred, Arrol, and Co., a firm incorporated especially for this task, and of which the late Sir William Arrol and Sir Thomas S. Tancred, a well-known railway builder, were prominent partners.

The undertaking aroused the keenest interest throughout the world, not only from its immensity, but because of the cantilever design which was adopted. The principle, however, is by no means new—in fact, next to the arch, it probably ranks as the oldest bridge-building principle in the world. Bridges of this character were common centuries ago in China, Tibet, and other little known countries, while I have seen crude structures of this type, which have been built by the Red Indians, thrown across yawning canyons among the mountains of North-West Canada.



PLAN AND ELEVATION OF THE BRIDGE

Not only did the new bridge eclipse anything previously attempted in these islands, but it was far and away more ambitious in its dimensions than anything hitherto completed in any other part of the world. Under these circumstances the engineers were deprived of precedents to guide them. Pioneering had to be carried out from beginning to end. Special devices, methods, and tools had to be evolved to cope with unusual conditions, and teasing problems had to be unravelled practically every day.

The first move in actual construction was the erection of the approach viaducts, and simultaneously the piers for the cantilevers. These latter were placed respectively on the Queensferry and Fife shores, while the central pier was built on Inch-

By courtesy of Messrs. Baker & Hurtzig.

BUILDING THE MIGHTY FABRIC OF STEEL: THE FIFE NORTH CANTILEVER, JULY 6, 1888.

This photograph conveys a vivid idea of the gigantic character of the work and the ingenious methods adopted in erection. At the bottom are the huge steel tubes which spring from the base of each cantilever pier.

garvie Island. At each of these places there are four cylindrical piers, and for the most part they were built upon the pneumatic caisson method. The sea-bed varied from boulder clay on the Queensferry side to rock on Inchgarvie Island and the Fife bank. The iron caissons were built on shore, launched, towed out to the site, and lowered. Despite the size and weight of these caissons, and the difficulties experienced in handling them when afloat, they were sunk successfully with one exception. While the fourth caisson for the South Queensferry pier was being handled, it tilted slightly, permitting the water to enter through the rivet holes. It became submerged, got out of control, and finally slid on the mud. It was an unfortunate mishap; nine months slipped by before the caisson was restored to the vertical position.

How the Piers were Sunk.

At the bottom of the caisson was a working chamber, 7 feet in height, where the excavators toiled, under compressed air. Admittance and egress were through the usual shafts and air locks. Owing to the character of the clay the caissons had to be sunk to depths ranging between 70 and 90 feet. At this depth the base of the piers is 70 feet in diameter, tapering gradually to 60 feet at low-water level, while they are spaced 155 feet apart in the case of the shore piers and 270 feet on Inchgarvie Island, from centre to centre. The material as removed from the sea bed was sent aloft in skips through the shaft to be dumped into barges. Work was continued uninterruptedly in shifts throughout the twenty-four hours, and, as a rule, from 200 to 300 skip loads were removed during the complete day by a force of from twenty to thirty men. As the soil was excavated the caisson settled lower and lower under the weight of the superimposed concrete until the requisite depth was gained, when the air shafts were filled up and the masonry upper work continued to the designed height above high water.

On Inchgarvie Island, as the subaqueous work had to be carried through rock to secure a level bench 70 feet below water, and as the caisson system just described was impracticable, owing to the slope of the rock, the base of the caisson was converted for the occasion practically into a huge diving-bell, 70 feet in diameter. As the men laboured in compressed air, at times a sensational spectacle was witnessed as the tide was falling. The water over the site became agitated and fussed like a boiling cauldron, owing to the pressure of the air within the working space of the caisson exceeding that of the head of water outside and accordingly securing its escape. These "blows" often were a source of excitement and dismay among uninitiated visitors, who conjured up visions of a terrible disaster among the drillers and blasters some 70 feet below.

The Gigantic Tubes.

From the centre of each pier rises a gigantic tube, or leg of steel, to a height of 343 feet. They do not rise vertically, but each broadside pair leans inwards. Thus at the base, looking through the length of the bridge, the tubes are 120 feet apart, but at the top they are 33 feet apart. These sloping columns are 12 feet in diameter, and at the base each sloping pair is connected by a horizontal tube of the same diameter. At the top the ends are connected by a box lattice girder, which likewise is 12 feet in depth. Additional strength is imparted by two diagonals formed of tubes 8 feet in diameter, thus imparting prodigious strength to the deepest part of the cantilever.

The Cantilevers.

From either side of this central section, or panel, the arm of the cantilever springs to a distance of 680 feet from the pier. Each bottom member of the arms comprises a steel tube 12 feet in diameter where it rises from the "skew-back" or

bed-plate on the piers, and tapers to 5 feet in diameter at the extremity of its overhang. At the piers these two members are spaced 120 feet apart, but as they lean out over the water they draw gradually together until at the end they are 31 feet 6 inches apart. The top members, comprising a pair of box lattice girders, taper from 12 feet square at the pier to 5 feet at the outer extremities, while they likewise bear inwards from 33 feet apart at the piers to 22 feet 3 inches at the ends. As they descend in their outward reach the depth of the cantilever, which is 343 feet at the piers, becomes decreased to 40 feet at the limit of the 680 feet overhang. These top and bottom members of the cantilever are strengthened by tubes, radiating, as it were, from the piers like the ribs of a fan in one, and by box lattice girders in the opposite direction, so that a diagonal system of bracing is obtained. In addition to this longitudinal bracing there is an intricate system of transverse bracing, the steel lattice work being of an elaborate character. Looking broadside at the bridge from a distance, it appears to be distinctly frail; but standing at one end of the bridge and looking through to the other, it appears to be an intricate maze of steelwork, so intricate, in fact, as to have prompted the remark that "one could not fire a bullet from a rifle across without hitting the steelwork somewhere."

The Connecting Girder.

But, except on those sides where the shore cantilevers reach out to join the approach viaducts, the overhang, 680 feet, is not sufficient to bring the arms together. In fact, there was a gap of 380 feet over the channel on either side of Inchgarvie. This gap is closed with a girder 346 feet 6 inches long, 41 feet deep at the end, and 51 feet deep at the centre, and weighing 872 tons. It was built out from either end of the opposite arms, and connected together 150 feet above high water.

The cantilever is secured to the piers by the aid of bed-plates. The upper part of each pier is provided with forty-eight steel bolts, $2\frac{1}{2}$ inches in diameter, sunk to a depth of 26 feet in the masonry. These bolts received the lower bed-plates, which comprised five plates of steel held together by countersunk rivets. Upon these were superimposed four layers of steel, constituting the upper bed-plates. Each set of bed-plates represented a weight of about 100 tons. Then the skew-back, some 40 feet in length, which unites in its grasp all the ten members of the cantilever, was riveted to the upper bed-plate.

Twice Built.

As might be supposed, the unique character and size of this bridge demanded the elaboration of special erecting methods. Practically speaking, the bridge was built twice: first piecemeal at the works on shore. The material was brought in its raw condition from the rolling mills to the contractors' shops, and there fashioned to the required shape and design. Special machines were built to meet every phase of the work. There were large mandrels to which the plates were bent for the tubular parts of the fabric, huge hydraulic presses for bending the plates, furnaces for heating the metal, drilling machines, and so forth. At first attempts were made to bend the plates in their cold condition to the desired curve, but this proved impracticable, so that a careful heating method had to be adopted. Every piece was fitted to its neighbour on shore, and every rivet hole examined by the engineers before it was passed. If an additional rivet hole were deemed necessary to make a good, sound job, the sanction of the engineers, who, metaphorically speaking, lived on the works, had to be obtained, and assent was not extended until its necessity had become fully recognised and it was found that the metal would not be weakened in the slightest degree by such action.

The engineers took no chances; they

Photograph by courtesy of Messrs. Baker & Hurtzig.

RAISING THE MASSIVE STEEL LEGS ON THE FIFE PIER, APRIL 15, 1887.

These huge tubes tower to a height of 343 feet.

were resolved not to be surprised by the development of something unforeseen at an unexpected moment. It was these elaborate cautionary methods which enabled work to proceed steadily and persistently once it was commenced, and which eliminated those periodical interruptions and hitches which often accompany undertakings of this calibre. The truth of the old saw, ' Make haste slowly," perhaps never was driven home more powerfully than in the building of the Forth Bridge.

One instance of this decision to risk nothing may be related. At the time the work was in progress knowledge of the effect of wind pressure upon bridges of large size, the caprices of the wind, its action, and, more particularly, its force in the Firth of Forth, were somewhat hazy. On the island of Inchgarvie, which is exposed to the full brunt of a gale coming from the east, Sir Benjamin Baker set up some wind gauges, the records of which were observed carefully and frequently. One was of large size, measuring 20 by 15 feet. In the centre of this surface was placed a tiny gauge, resembling a door, with a superficies of about 2 feet, while it was flanked on either side by another gauge. On each shore other gauges were set up. Some very remarkable results were noticed. Thus when the large gauge was registering a pressure of 12 pounds per square foot it was found that the little gauge at the same time recorded as much as 25 pounds per square foot. This served to show that there is a tendency for the wind to act something after the manner of a jet of water. At other times, when the Inchgarvie gauge registered a pressure of 34

ounds per square foot, the shore gauges would show anything from 12 to 22 pounds per square foot, proving conclusively that the strongest blows come in puffs, or are felt over only a comparatively small area. The sum of these practical observations certainly tended to show that the wind is far more liable to affect a small rather than a large bridge adversely, because in the latter case there is less likelihood of the whole structure becoming engulfed in the zone of the most powerful wind effort. So far as the Forth Bridge is concerned, exposed as it is broadside to the wind blowing through the Forth funnel, it is not likely to experience any ill-effects, inasmuch as the minimum of resistance is offered, owing to the open character of the fabric, as compared with its transverse section.

The setting of the steel likewise was carried out upon ingenious and novel lines. Scaffolding was impossible. Instead, in the case of the central section of each cantilever, the work was carried out from the base to the top by means of a vertically travelling platform, whereon the handling machinery was placed; while cradles, or cages, were placed around the tubular columns for the riveters and their machines. The men were lifted and lowered by means of hoists and cages, similar to those employed in mines, so that the minimum of time was lost in getting from and to the working areas, while the material was handled with the maximum of expedition. So successful were these arrangements that the centre portion of the Queensferry cantilever was built up to its full height of 281 feet in about twenty-four weeks. Similarly, in running out the bottom members of the cantilever a cage was erected around the outer end of the growing tube on which a crane was mounted, while the cage itself contained the riveting machinery and small special heating furnaces. This cage did not move along a run-way; but, as the tube advanced, the back part of the cage was dismantled and re-erected at the forward end, this procedure being repeated until the erecting work was completed.

Photograph by courtesy of Messrs. Baker & Hurtzig.

THE QUEENSFERRY MAIN PIER. NOV. 7. 1888.

The task of connecting up the arms of opposing halves of a span in such a huge structure as this is extremely delicate. A mass of steel, 855 feet in length, which represented one moiety from end to end, has a pronounced stretch under the action of the sun's rays. The calculations necessary to enable connection to be accomplished with the minimum of delay were made, and the closing lengths, or key pieces, were carefully prepared. A cloudy day, when the temperature was equable, was selected for the task, and the breaches were closed in accordance with the prearranged plans, without the slightest hitch. Moreover, the details were prepared in such a manner as to enable the key piece to be completed, and the temporary connection to be cut away, in a few hours.

The First Man Across.

An interesting story in connection with this part of the work may be related. The task advanced more rapidly on the Queensferry than on the Fife bank, so that on September 26th, 1889, the two arms on the latter side were ready to be closed. There was a keen rivalry among the workmen on the opposite ends of the meeting arms to be first across the gap. Two men decided to steal a march upon their fellow workmen, and one of this twain was resolved not to share the glory with anyone if he could help it. The only thing was that he could not get rid of his colleague, who clung to his side. Suddenly a brilliant idea occurred to him. They had a ladder, that was just long enough to reach across the breach if only a rope could be obtained to lash it at one end. The second man, all unsuspectingly, hurried off to find a rope, but his comrade, shouldering the ladder, laid it across the jibs of the cranes working on the end of each arm. It held, and he crawled across this dangerous gangway, some 200 feet above the water. The feelings of his companion when he returned with the rope to find his chum had done the deed may be imagined.

Triumphant Tests.

The railway tracks are laid on a viaduct which runs through the cantilevers. There is a double road, with a gangway on either side for workmen. The bridge was subjected to severely exacting tests in February, 1890, under direction of the Board of Trade, from which it emerged triumphantly, the maximum deflection on the ends of the cantilevers of the main spans being only 7¾ inches and 1⅝ inches at the central girders. The following day a furious gale swept the Firth of Forth, but the bridge stood as firmly as a rock. The official opening took place on March 4, 1890, when King Edward VII., as Prince of Wales, drove the last rivet in the middle of the northern main girder.

Expenditure £3,000,000.

By the time the structure had been completed some £3,000,000 had been expended, of which the bridge proper absorbed about £1,700,000, the plant and general charges some £800,000, and the connecting roads of railway £500,000. Over 54,000 tons of steel were worked into the fabric. The Inchgarvie piers support 18,700 tons, and the other two piers 16,130 tons each. To hold this mass of steel together, about 6,500,000 rivets, representing over 4,000 tons, were required, and 40 miles of steel plates were used for fashioning the tubes. In addition, 740,000 cubic feet of granite masonry, 46,300 cubic yards of rubble masonry, and 64,300 cubic yards of concrete, and over 21,000 tons of cement, were utilised. When work was in full swing an army of 5,000 men found employment, and so carefully were they tended, and so complete the precautions adopted to ensure their safety, that only fifty-seven men lost their lives through accident.

Yet, although the bridge is sufficiently strong to withstand a tornado, it is susceptible to the insidious ravages of an implacable enemy—corrosion. In order to frustrate this attack the bridge has to be given a

Photograph by courtesy of Messrs. Baker & Hurtzig.

GENERAL VIEW FROM THE SOUTH SHORE OF THE WORKS, SHOWING THE THREE MAIN PIERS, AUGUST 2, 1887.

protective coat. This task is one of some magnitude in itself, seeing that the area of steelwork which has to be treated aggregates approximately 135 acres. The work has been in constant progress since the year 1883, and about three years are required to give the whole of the fabric one coat. In accomplishing their work the painters use over 40,000 pounds of paint during the year.

Seeing that the steel highway which carries the train is continuous for a length of 4,800 feet, there is a considerable movement of the metal under the fluctuations of temperature. The total allowance for expansion and contraction is 8 feet 4 inches, there being four expansion joints on each track of the cantilever sections.

For twenty-two years this wonder of engineering ingenuity and magnificent workmanship has withstood the stress of heavy traffic, wind, and storm, yet not the slightest sign of weakness has been revealed nor a single repair effected. It ranks still as the finest example of bridge building ever consummated, and is one of the few bridges in the world over which the heaviest express trains can rattle at a speed of 60 miles or more per hour in perfect safety.

Photograph by courtesy of Messrs. Baker & Hurtzig.

CREEPING OUT OVER THE WATER: THE MAIN PIER, DEC. 20, 1887.
Each arm has an overhang of 680 feet.

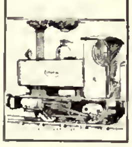
An attempt to eclipse this wonder of British engineering is being made in Canada, with a bridge which is to span the River St. Lawrence just above the City of Quebec; but this structure, taken on the whole, will not exceed the Scottish work except in one particular—the length of the span. This latest bridge is to carry only one set of rails, and the train speeds are to be restricted severely.

From the railway point of view the Forth Bridge has been a complete commercial success. It is worked and maintained by the North British Railway.

ON THE STEEPEST PART OF THE RAILWAY ABOVE THE TIMBER LINE, WHERE IT RISES 1 IN 4, SHOWING THE SPECIAL TYPE OF LOCOMOTIVE.

The Pike's Peak Rack Railway

A LINE WHICH CLIMBS A MOUNTAIN 14,147 FEET HIGH



WHEN, in 1806, Captain Zebulon M. Pike first beheld from afar the majestic proportions of the peak which now bears his name, rising above the dishevelled mountainous knot found in the State of Colorado, naturally he sought to scale its topmost heights. But his determination and endurance proved insufficient for the task. This is not surprising, seeing that he was not equipped for an exacting mountaineering expedition, whilst this hoary old man of the American Rockies is no mean crest, seeing that it beetles 14,147 feet into the clouds.

After the conquest of the Rigi and other Alpine crests in Europe, enterprising Americans, resolved not to be eclipsed by the Old World, suggested the railway subjugation of Pike's Peak. The proposal was startling, as this is a remarkable mountain. It is not a mere jagged nose of rock thrusting itself higher from its fellows into the sky, but lifts its head above a broad expansive plain. As a coign of vantage its crest is difficult to surpass in North America, because wonderful vistas of unparalleled magnificence are unfolded over an area of 60,000 square miles.

From the viewpoint of the railway engineer it possesses many attractions, inasmuch as it not only indicates the highest point between the two poles to which the rack railway has been carried

for tourist purposes, but the consummation of the task bristled with extraordinary difficulties.

The engineer was spurred to its mastery with the ribbon of steel by the striking stories of beautiful panoramas which were related by the few mountaineers who toiled afoot to its summit. Could the requisite financial assistance be raised to carry a line from base to crest? That was the problem. There was no anxiety about sufficient traffic being forthcoming to render the undertaking remunerative. If the crest were brought within the reach of the masses, who are not prepared to experience the hardship and peril of climbing among ugly crags, and braving the unpropitious elements, thousands would avail themselves of the opportunity to proceed to the top by rail, providing the element of safety were above suspicion.

The First Scheme.

So reasoned an enterprising engineer in 1884. He succeeded in infusing a number of colleagues with his enthusiasm, and a start was made. The promoters of the scheme essayed to scale the mountain with a maximum grade of 1 in 20, and to achieve this end plotted a circuitous route 30 miles in length, in which distance 7,518 feet in altitude were to be overcome, Manitou, the starting point, being at an elevation of 6,629 feet above sea level.

The railway was forthwith commenced, but when it had been graded a distance of eight miles, and was ready to receive the metals, the scheme was assailed vigorously on technical grounds. This unexpected criticism dried up the fount of financial support; the project had to be abandoned.

The Rack-rail Adopted

The triumphs of the Swiss engineers with the rack railway and the widespread successes, from the commercial point of view, that were being reaped by the provision of transportation facilities to inaccessible heights caused the Pike's Peak project to be resuscitated. But the new project was vastly dissimilar from that originally evolved. The fathers of the new idea decided to follow the shortest practicable route between the base and crest of the mountain. The maximum gradient would be steep: that, however, was of secondary importance, seeing that the cog-wheel system could be adopted.

The preliminary surveys were run in 1888, the greater part of the year being occupied in this initial task. The little band of men spent a racking time among the precipitous cliffs, over which they were slung by chains to toil upon narrow ledges scarcely wide enough to permit one to turn round, scrambling over ragged crags, facing biting winds, blinding snows and lashing rains. Their physical endurance and nerve were taxed to the utmost; accidents were frequent, and thrilling escapes numerous. But they completed their work successfully, and the sum of their efforts showed that there were no insuperable reasons why the two extremities of the peak should not be connected by a steel link some nine miles in length.

The Snow Trouble.

The surveyors emphasised one drawback. "There will be snow, and plenty of it, against which to contend." This factor had been brought home to them with painful reality. Banks 30 and 40 feet in depth were by no means uncommon. Often they had been forced to tunnel their way through the heavy white blanket which wreathes Pike's Peak for more than six months in the year.

The trials and tribulations that would confront the navvies in the higher reaches were not exaggerated, but they were fully indicated. The rarefied atmosphere taxes the lungs when one is engaged in physical exertion. On the summit the barometer stands at about 17 inches, and water boils at 184°, instead of 212° F. It was realised that labour would be very exhausting, but the promoters concluded that by

handling the men carefully this disadvantage could be mitigated very appreciably.

It was decided to use the Abt rack system, which had proved so successful in Europe, upon the plans outlined by the surveyors, but the apprehensions of the timid were not overlooked. "There must be no suspicion of danger," urged the guiding spirit of the enterprise. "The line must be built as strongly as possible; every device to ensure unquestionable safety in travelling must be adopted regardless of expense, so that the most nervous passenger may feel just as secure when climbing up a bank of 1 in 4 as when riding over level ground in a railway car." This adjuration was carried out to the letter. Nothing was left to chance; nothing completed in a perfunctory manner. The Pike's Peak Railway stands among the most substantially built lines of its class in the world. The United States tourist is not so familiar with mountaineering by rail as travellers in Europe, and the idea of crawling to a height of 14,147 feet above sea level, while fascinating, inevitably provoked certain misgivings in the early days.

The Track.

The railway builders started on their task from Manitou in 1889. The first stretch was comparatively easy, as it ran among the foothills, but as the mountain flank proper was attacked, the difficulties became greater and greater. In the lower levels the route threads dense timber expanses, where the right-of-way was found littered with huge piles of logs and trees which had been brought to the ground by the enraged elements. Official requirements stipulated for a road-bed varying from 15 to 20 feet in width, down the centre of which the track was laid. This is of the standard gauge, the side rails carrying the wheels which guide and support the weight of the trains weighing 40 pounds per yard. By making the road-bed the foregoing width there is ample clearance on either side of the coaches. The permanent way is of the most solid description. Where culverts were required to span some little rivulet or creek, stone was used; where bridges were necessary to traverse a larger cleft in the mountain side, steel was employed. No timber trestling whatever was introduced. The road-bed itself is laid upon the solid rock, and is ballasted heavily to secure complete rigidity for the metals, so that they may not be displaced easily by any of the disturbing influences of Nature, which sweep the peak continually, and which are especially severe during the winter.

The Rack-rail.

The rack-rail itself is made from the finest Bessemer steel, with the teeth cut from the solid mass of metal by machines which were designed and built specially for the purpose. It is built up in lengths of 80 inches, and varies in weight from 63 to 95 pounds per yard, or an average of 98 tons per mile. The specifications insisted that each tooth of the rack when cut should be within one-fiftieth of an inch of the size stipulated.

The rack-track comprises two of these rails laid side by side centrally between the outer metals, and set $1\frac{5}{8}$ inches apart. The ladder is secured to the permanent way by means of four bolts—two in the centre and one at either end of each length—to three die-forged chairs, which in turn are bolted heavily to the sleepers. These latter are of extra length and weight, and are spaced more closely together than in ordinary railway practice. The rack-rails are so laid that the joints of each length do not come in line, while the teeth of one is brought opposite the space between two teeth of the other. This ensures the two double wheels of the locomotives securing an even bearing at all times, and is conducive to smooth travelling.

The railway measures 47,992 feet in length from end to end. The average gradient is 844·8 feet per mile, the maxi-

mum rise being 25 in 100. The sharpest curves are of 16°, that is, a radius of 358 feet. In order to contribute to the rigidity and solidity of the track, and to prevent it moving or sliding under its own weight, which is enormous, or by the forces of sudden expansion and contraction of the metal, it is anchored to the solid rock at distances ranging from 200 to 1,400 feet, according to the severity of the gradient; 146 of these anchors are used throughout its entire length.

A CHARACTERISTIC DEFILE ON THE PIKE'S PEAK RAILWAY BELOW THE TIMBER LINE.

It was when the timber line was passed that the greatest trials and hardships in construction were encountered. The mountain surface was scarred in a terribly rough manner. Here projecting pinnacles, with their sides as polished as a mirror by the elements, had to be blown away; there ledges had to be cut in the side of the solid rock-face; enormous shoulders had to be rounded and defiles threaded. The men engaged in the work suffered privations innumerable. They had to clamber and toil among ragged masses of rock which strewed their path, had to face intense cold, and to stand or crouch against cutting winds, which at times sweep over this peak with tornado-like fury. Often they had to hew their way through solid masses of packed snow and ice, while the stinging hail and blinding rains repeatedly drove them to seek what little shelter they could. Camps were laid low time after time, and frequently, owing to the ravages of the elements rendering the mountain impassable, they had to subsist on meagre fare, as the bulk of their provisions became exhausted. Near the summit the prevailing low temperature, combined with the rarefied atmosphere, played sad havoc even with the strongest constitutions. Time after time, after fighting a stern uphill battle against the relentless elements for hours, the men were compelled to throw down their tools from sheer exhaustion, and were forced to seek a short respite in the lowlands to recuperate their wasted energies. Notwithstanding these heavy handicaps the last rail was

laid on October 20th, 1890, and the line was opened for traffic on June 1st in the following year.

As may be supposed, the engine in making such a continuous and heavy pull towards the clouds develops an intense thirst. The water supply at places was a searching problem, but it has been met effectively by three large tanks which are provided at intervals. The locomotives are somewhat quaint-looking, albeit powerful, mechanical triumphs. They are of the four-cylinder Vauclain compound type, the high-pressure cylinders being 10 inches and the low-pressure cylinders 15 inches in diameter, the stroke being 22 inches. Steam is carried in the boiler at a pressure of 200 pounds per square inch. There are two steel cog-wheels through which the propelling effort is transmitted, and which grip, or mesh, with the rack-rail.

On such a railway, abounding with numerous steep banks, the braking arrangements necessarily are of supreme importance. From the sides of the driving cog-wheels extend four corrugated surfaces upon which the powerful steam and hand brakes are applied. Any one of these brakes is sufficient to bring the train to a standstill, even upon the steepest sections. The Le Chatlier water-brake is also fitted to the steam cylinders, these being used on the descent as air compressors to regulate the speed of the train.

The coaches are of the American observation Pullman pattern, and for such a railway are luxurious. The seats are not tilted but arranged in such a way that the passenger always has a level position Each car is able to accommodate fifty passengers, and if necessary it can descend the mountain without the aid of the locomotive, because each bogie carries cog-wheels engaging with the rack, through which powerful individual braking can be applied to secure complete control. This enables the coach to be stopped instantly and independently of the locomotive. As is usual upon rack railways, the engine pushes the coach up hill, and precedes it

VIEW OF THE TRACK OF THE PIKE'S PEAK RAILWAY, SHOWING THE RACK-RAIL.

on the descent, the two never being coupled together.

Between the two terminal points there are six intermediate stations, each of which provides facilities for viewing some scenic spectacle. After the timber line is passed at 11,578 feet, the railway enters upon its steepest, and at the same time the wildest part of its journey, to the summit station, beside the Government signal station. One very curious effect often is observed when climbing the mountain. Every inch of the road is uphill, and yet after toiling up a steep bank, and when about to enter a stretch of more moderate gradient, the road ahead appears to run downhill. The round journey—up and down the mountain—a distance of approximately 18 miles, occupies some three hours.

Though innumerable obstacles had to be overcome to bring about the realisation of the Manitou and Pike's Peak Railway, they are equalled fully by the herculean efforts that have to be put forth to open and maintain the line during the season.

THE CREST OF PIKE'S PEAK, 14,147 FEET ABOVE THE SEA: THE ENGINE IS ATTACHED AS A "PUSHER."

"Snow," narrated Mr. Sells, the chief engineer, to me, "is our greatest bugbear, and it is of a nature seldom experienced upon any other railway. On the upper five miles it runs from 3 to 35 feet in depth, and it packs as hard as masonry. Running through the banks are stratæ of ice, representing the packing of the heavy snows during the winter. It is these frozen layers which tax our efforts so severely. There is no mechanical appliance which can cope with them. What we do is to cut trenches so that the mass is divided into blocks about 9 feet square. These are then transferred to a flat car by a scoop-nose plough, which we have designed specially to deal with this work, and pushed by one of the locomotives. We can get two of these blocks on a car at a time. The train with its load then drops back along the line until it reaches a point where the railway overlooks a ravine. After cutting an opening through the solid off-side wall of icy snow beside the track, the men, by means of large wooden levers, prise the blocks off the

deck-car to send them tumbling down the mountain side. It is slow, trying work, often accomplished in the face of a biting wind, but it is the only way in which we can get the line open for traffic.

" Above the timber line the snow drifts easily, as there are no obstacles to its scudding race over the mountain slopes. In some seasons we have had to open the line as many as fifteen times. June 1st is the scheduled day on which the first train runs to the summit, and as a rule we are not troubled with snow after the 15th of that month. But occasionally we have to haul out our snow-clearing tackle throughout July, during which month, sometimes, very heavy falls take place."

"Sunrise Excursion."

Despite these drawbacks, and although the railway is open only for a very brief period, it is a hot favourite with tourists. During the height of the season the company maintains what it calls a semi-night train service. One leaves the lower terminus late in the afternoon and reaches the summit in time to witness the gorgeous spectacle of the setting sun, and, spending the night at the comfortable Summit Hotel, is able to view the equally enthralling dawn of another day. One of the most popular trips is the weekly " Sunrise Excursion," which, leaving the lower terminus at midnight, lands the travellers at the crest in time to see Old Sol creep over the Eastern horizon. In fact, this special service has developed to such a degree that often the entire equipment of the railway has to be impressed to cope with the crowds.

Notwithstanding the complete success of the Pike's Peak Railway, the rack system has not been utilised very extensively in the United States. Even the first railway of this type, that up Mount Washington, in New Hampshire, is doomed. Another route has been surveyed, and it is intended to lay down an electric road working throughout by adhesion purely and simply. Still, the Pike's Peak line possesses a unique distinction. It is the longest continuous road built upon this principle in the world. In view of the fact that the rack railway is being superseded, at all events for mountaineering purposes, by cheaper systems for achieving the same end, it is very doubtful whether this line ever will be eclipsed.

Most Costly Rack Line.

The total cost of the undertaking was £200,000, representing an average of £22,000 per mile, so that it ranks as one of the most expensive rack lines which has been laid down in any part of the world. Since its completion in 1890 it has been the means of conveying thousands of travellers to the mountain top. From the European point of view, and bearing in mind the comparatively low fares charged on the Swiss mountain rack railways, the ascent of Pike's Peak by this medium appears somewhat expensive, the return journey costing 20s., or over 1s. 1d. per mile. But bearing in mind the cost of construction, the heavy maintenance expenses, and the brief period of the running season, in conjunction with the fact that it is essentially a pleasure line, the fare is by no means excessive.

" Since this line was opened," proudly confesses the engineer, " we have never had a single personal injury arising from its operation. It cost a lot to build, but absolute and unquestionable safety was the factor which guided its consummation, so that not even the most timid need entertain the slightest apprehensions. 'A substantial road' was our watchword, and the policy has been repaid amply by the complete financial success of its operation."

A BLEND OF EAST AND WEST: THE STATION AT UTARADIT.
The Oriental style of architecture is followed in the façades of the station buildings

The Railway in Siam

THIS EASTERN KINGDOM, FOR SO LONG A "SEALED BOOK," IS NOW BEING OPENED UP TO COMMERCE BY A VAST SYSTEM OF GOVERNMENT RAILWAYS

IT was not so many years ago that the vast tract of territory, measuring 1,100 miles in length by 506 miles in width, which occupies a large section of the Indo-China Peninsula, and which is known politically as the Kingdom of Siam, was as closed to the handmaids of civilisation as the South Sea Islands. The traditions, characteristics, and customs of the country were decidedly adverse factors to development. The natives were content to cultivate rice, both as a staple article of diet and also for export; they made little effort to exploit the other resources of their country. The teak forest for years went untouched, the luscious fruits practically rotted, while the minerals for the most part were left dormant. At the same time attempts to invade the country and to turn its latent wealth to commercial advantage were fraught with considerable dangers to Europeans. The hostility of the natives, although pronounced at times, was not to be feared so much as the climate of an unopened country and the untamed jungle, where wild animals of all descriptions abounded.

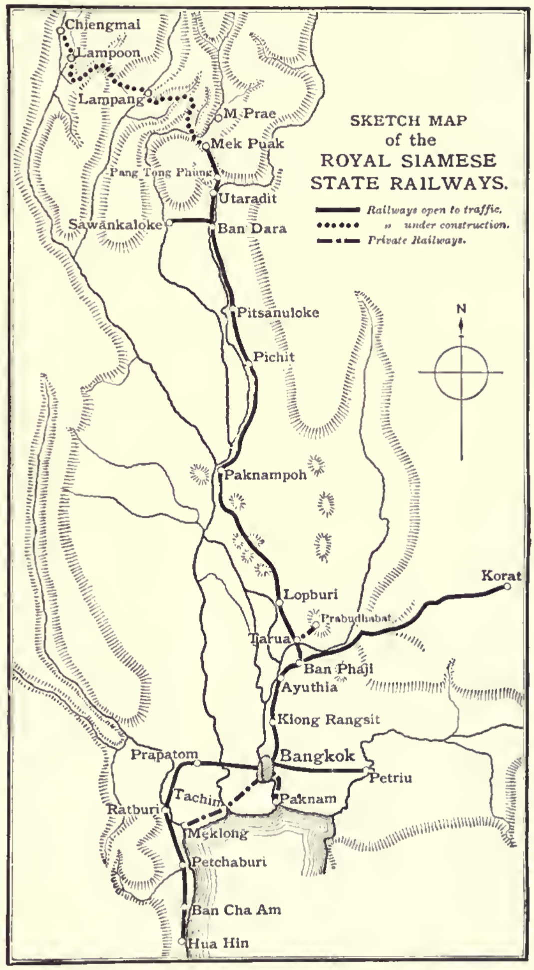
The country beyond the immediate

purlieus of Bangkok, the capital, was virtually a closed book. Even the natives themselves knew very little about it. The interior means of communication were by raft or boat along the waterways, while the area of development in the hinterland was restricted severely to the lower-lying cleared land immediately contiguous to the arteries of water travel. Primitive bullock wagon roads had been driven here and there to link up isolated points, but such evidences of enterprise were few and far between. The result was that the greater part of the interior was nothing but a vast stretch of undulating, matted jungle, such as is only to be found in the tropics, which never had been penetrated.

Towards the latter part of the nineteenth century, however, King Chulalongkorn I., whose mind and view of things had become broadened by his associations with Europe, embarked upon a liberal policy with a view to ameliorating the conditions of his people.

His Majesty grasped the fact that the unlocking of the country would proceed very slowly and fitfully unless improved ways and means of moving to and fro were adopted. The waterways were too slow and uncertain. Railways obviously offered the only possible satisfactory solution to the situation. The provision of these facilities came under serious consideration about the years 1887–8, and, through the efforts of Sir Andrew Clarke, formerly Governor of the Straits Settlements, a contract for carrying out surveys for a railway system was placed with an English firm. Extensive surveys were driven from the capital as far as Chieng Sen on the northern frontier. This was an ambitious proposal, but it was proved that the scheme offered no insuperable difficulties, and would not be inordinately costly, while it would provide the country with a steel backbone, and connect the capital to a strategical point for the interchange of commerce with Burmah, China, and Upper French Indo-China. The Government proposed to defray the cost of construction and upon completion to work it as a State undertaking.

Owing to their comprehensive nature, the surveys, extending through difficult country, occupied considerable time. Meanwhile, private enterprise, realising the trend



of affairs, determined to profit from the favourable attitude of the Government. The former approached the authorities for permission to build a line from the capital to Paknam, near the mouth of the Menam Chao Phya. The concession was granted, the Paknam Railway Company, Limited, was incorporated in Bangkok, and the construction of the road was commenced on July 10th, 1891. It was an unpretentious undertaking, comprising a line only

$12\frac{1}{2}$ miles in length, but it was the pioneer railway of Siam, and its opening for traffic in 1893 was received with widespread jubilation. It met with instant success, and from the very first proved an excellent investment to its shareholders.

The First State Line.

It was decided to inaugurate the Government scheme by building a line from Bangkok to Korat. The first sod was turned by King Chulalongkorn on March 8th, 1892, amid wild rejoicing. Inasmuch as the State Department possessed no facilities at the time to carry out large railway building projects, although a department was in course of formation, the enterprise was handed over to a contractor to complete.

The standard gauge of 4 feet $8\frac{1}{2}$ inches was adopted, and the European model was followed as closely as the circumstances would permit. The route ran through the Menam River valley to Ayuthia, where it swung sharply to the east to ascend the Korat plateau, which varies from 400 to 1,000 feet above sea level. Work, however, did not proceed so smoothly and rapidly as was desired, but the contractor was handicapped somewhat by the dearth of labour. Dependence had to be placed almost entirely upon Chinese coolies, and these had to be taught the mysteries of railway grading. Probably the inability of the contractor to cope with the labour problem was responsible for his slow advance. At all events, after he had been engaged some four and a half years upon the task it was taken out of his hands by the royal Railway Department.

The State engineers succeeded where the contractor had failed, and they speeded up the constructional work so effectively that the first section, from Bangkok to Ayuthia, was opened by the King on March 25th, 1897. The engineers pushed on along the location selected and by the latter part of the same year had reached Gengkoi, the half-way house to Korat. Immediately this section was completed a daily service of trains for both passengers and goods was inaugurated. Without pausing, the builders drove forward, and so rapidly that in November, 1900, the first State Railway was completed. Korat was in railway touch with the capital, and the service was extended to this point, the length of the line being 165 miles.

The Northern Railway.

Upon the completion of this eastern railway the original longitudinal or Northern Line, which British engineers had surveyed in the late 'eighties, when the railway was first discussed, was taken in hand. The Korat line, by running parallel with the Menam River, ran northwards for nearly 60 miles. Thereupon it was decided to continue construction from a suitable point on this railway. A station, Ban Phaji, between Ayuthia and Prak Preo, $56\frac{1}{4}$ miles out of Bangkok, was selected as the junction, and the line was carried a further $26\frac{3}{4}$ miles to Lopburi. As no particular difficulties of a technical character were encountered upon this section, it was completed speedily, and opened for traffic on April 1st, 1901.

The Question of Gauge.

Although the Northern Railway may be said to constitute the favourite and greatest project of the Government, another line had been commenced in the meantime. This is the Southern Line, running westwards from Bangkok, via Nakonchaisi to the Meklong River, whence it bends southwards, crosses the waterway, and follows the coast through Ratburi to Petchaburi, $94\frac{3}{4}$ miles. Commenced in 1899, and despite the fact that long bridges had to be thrown over the Tachin and Meklong Rivers, this line was opened by the King of Siam on June 19th, 1903.

When this line was discussed the question of gauge arose. Hitherto the Government had decided in favour of the standard British gauge for its system, but as the Southern Line is destined to link up with the railways of the Federated Malay States, which favours the narrower gauge

of 1 metre, it was recognised that if the broad gauge were adopted a break in the railway journey would have to be made at the frontier. The Siamese Government also foresaw that, in accordance with railway expansion, the opportunity to link up with the railways in Lower Burmah would be inevitable, and the Burmese Railways are also of the metre gauge. Consequently, in order to secure as smooth interworking as possible when junctions were effected with its two neighbours, the Government decided to adopt the same gauge. At the same time it was laid down that all railways built on the west side of the Menam Chao Phya River should be of metre gauge, the wider, or standard, gauge being restricted to railways built on the eastern side of this waterway. Thus, when the systems of the different countries meet, through direct working will be possible between points in Burmah, the Federated Malay States, and Bangkok. The wisdom of this policy cannot be overestimated, inasmuch as it will be to the benefit of all the countries affected, and will conduce to overland travelling between Farther India and China.

THE TASK OF THE RAILWAY BUILDER IN THE SIAMESE HINTERLAND.
The track through the jungle, north of Utaradit.

A further section of the Northern Line was now taken in hand, viz. from Lopburi to Paknam Poh, 73¾ miles. In the original scheme it was proposed to take advantage of the river valley, but a revision was made. A few miles to the east of the waterway there is a large and very rich stretch of rice-raising country, and so, for the purposes of developing this territory, it was decided to run the line straight through the centre of this district, since there is a rich traffic immediately available on both sides. This was a wise decision, seeing that rice is to Siam what wheat is to Canada—the staple industry of the country and the chief source of revenue to the railway.

About this time the value of the railway began to be felt. The original line to Korat had been outgrown by the traffic which had arisen. Heavy expenditure was incurred in the enlargement of the yards at the various stations, while the rolling stock had to be increased considerably. Th[e] outlook, indeed, was so promising that th[e] Government decided to build a new line running almost due east, from Bangkok t[o] Petriu on the west bank of the Bang-pa[-]kong River, a distance of 39½ miles. Thi[s] road runs through a rolling and highly fertile country, capable of rich development, and the railway should prove highly remunerative. The first section of this line was completed in January, 1908, while the same month recorded the opening fo[r] traffic of another stretch of the Norther[n] Line from Paknam Poh to Pitsanuloke.

A TEMPORARY CONSTRUCTION BRIDGE.
The engineer's "special," showing his "saloon," drawn by a wood-fired small tank engine.

As the Northern Line advanced farthe[r] and farther inland, the engineers drew towards the more difficult and mountainous country which fringes the northern hinterland of Siam. By hugging the east ban[k] of the Menam River a favourable, tolerably easy, and cheap location was obtained from Bangkok to Ban Dara, to which

point the line was opened on November 11th, 1908. Hitherto expensive bridging had been eliminated; but now, in order to secure the advantages of the natural pathway for the steel highway to Utaradit, the next objective, and a place of considerable importance, it became necessary to swing across the Menam River.

BRIDGE-BUILDING IN THE SIAMESE JUNGLE.
The coolies' camp of native huts is seen below the bridge.

As the level of this waterway fluctuates considerably according to the wet and dry seasons, a long bridge was necessary. The surveys emphasised the necessity of a structure 861 feet in length, divided into three spans. By this arrangement the erection of the brick piers was facilitated during the dry season, dispensing with elaborate plant in carrying out the foundations. The contract for the bridge was thrown open to the world, but in the face of severe competition was secured by the well-known British firm, the Cleveland Bridge and Engineering Company, of Darlington, which, it may be recalled, has been responsible for the Victoria Falls, Upper Nile, and other important bridges. The contract called for the supply of the steelwork only, as erection was to be carried out by the royal Railway Department.

The bridge is of the cantilever type, each anchor arm, or shore span, being 264 feet 6 inches in length. Each anchor arm and the pier panels were built on timber falsework, while the overhanging section was carried out from either pier for a distance

of 116 feet, bringing the length of the main span to 332 feet.

The northern extension was completed to Pang Tong Phung, beyond Utaradit, by August 15th, 1909. Also a spur had been built for 18 miles westwards from Ban Dara to Sawankaloke, the head of navigation on the Meh Yom River. The linking of Utaradit, which is the most important up-country commercial centre, with Bangkok constituted an historic event in the history of the country; indeed, the necessity for such communication had been the main reason why constructional work had been pushed forward so vigorously on the Northern Railway.

The Menam Plain, which is traversed by the Northern Railway, practically ends at Utaradit. Thence the ground rises rapidly, and in a very broken manner, into the mountain range. The lower slopes are covered with an extremely dense and matted tall-growing vegetation, so that clearing became an expensive, difficult, and tedious task. The authorities, recognising that work on the mountain division therefore was certain to be heavy and complex, decided, in April, 1909, to postpone further advance for a time. Although Utaradit was nominally the extreme terminus, the railhead was a little distance beyond. Utaradit was a strategical commercial centre, inasmuch as the caravans engaged in the mountain traffic started from here, threading the mountains by the wearisome Kao Plung Pass to Phrae. This traffic formerly was very heavy, and the pass was a busy highway. The wagons were supplemented by pack animals and carriers, these latter being engaged for the most part in traversing the lesser-known districts, following perilously difficult trails. Transport charges were high, and only goods of value could be handled, as it was not worth while to move cheap articles by such means. Consequently the territory suffered, inasmuch as those very commodities for which there was the greatest demand could not be taken through the mountains over the high roads, as the prices were swollen by the cost of transport to a level out of all proportion to their worth.

CANTILEVER BRIDGE OVER THE MENAM, NEAR BAN DARA, ON THE NORTHERN RAILWAY OF SIAM.

But the urgency of continuing north

ward became forced upon the authorities more and more as time progressed, inasmuch as the railway was bringing goods up country at such cheap rates, and so quickly, as compared with the slow water route, that Utaradit was becoming congested. Accordingly work was resumed upon a further 12 miles from Pang Tong Phung, at the foot of the range, to Meh Puak, on the northern slopes, and convenient to Phrae. This broken ridge divides the watersheds of the Menam Yai and Meh Yom Rivers. It was no easy matter to decide the route which should be followed through the barrier. Each pass was investigated minutely to discover the cheapest and most practical crossing. In addition to driving surveys from Utaradit, others were made along the Meh Yom River from the head of navigation at Sawankaloke to Muang Long, via the Muang Long and Pang Buei Passes, while detailed surveys were made through the Muang Li Pass between the Meh Wang and the Meh Ping. After the problem had been threshed out in all its bearings, however, it was decided to cross the ridge by way of the Kao Plung Pass, which was that taken by the highroad.

Extension Northward.

Anticipations that the ridge would be difficult to overcome were fulfilled. It proved the most difficult section encountered in the whole railway building programme, especially the first five miles out of Pang Tong Phung. The metals had to be lifted 600 feet in the course of the $16\frac{3}{4}$ miles between Utaradit and the Kao Plung Pass. The broken character of the mountain-sides rendered the earthworks very heavy, and many perplexing technical difficulties had to be solved. It was a case of cut and fill for the greater part of the way, many cuttings and embankments, running up to 85 feet in depth and height respectively, having to be carried out. In one stretch of 3,300 feet, just below the summit of the pass, this work assumed such a heavy character that, in order to avoid a cut 100 feet in depth through a pinnacle, followed immediately by an embankment of the same depth across a fissure, a tunnel, $357\frac{1}{2}$ feet, was driven through the spur, while a viaduct, 270 feet long, was thrown across the gorge. Owing to the water encountered, this tunnel had to be lined with brick from end to end.

The Drive Through the Mountains.

Bridging would have been adopted more extensively upon this section but for one restraining factor — transport charges from the railhead to the grade ahead. These were so abnormally high that, when the cost of cuttings and embankments was compared with steel and masonry structures, such an overwhelming advantage in point of cost prevailed in favour of the earthwork that it had to be adopted, except in exceptional cases.

Bridging Difficulties.

The railway overcomes the Kao Plung Pass by a tunnel 1,188 feet in length, and about 230 feet below the wagon road over the pass. Owing to trouble with water this tunnel had to be lined throughout, concrete being used for this purpose. The alignment through this ridge constitutes a striking piece of surveying, since, despite the abrupt rise, it was found possible to keep the maximum gradient to 1 in 50. Even the easiest section upon the mountain division of $4\frac{1}{2}$ miles between Pang Tong Phung and the summit of the pass is 1 in 66, while the sharpest curves have a radius of 656 feet.

The Kao Plung Tunnel.

The mountain section of the Northern Railway between Utaradit and Meh Puak on the northern side of the pass, 24 miles, has proved to be the most expensive to build upon the whole of the royal Siamese railway system. The total cost of construction and equipment was £224,381,* representing an average of £9,348 per mile.

* Reckoning the Siamese Tical at 1s. 2d. British currency.

The total volume of earth and rock which had to be turned and blasted amounted to 2,220,121 cubic yards, at a cost of £92,848 — approximately 8d. per cubic yard.

Influence on Trade.

The railway was opened as far as Meh Puak on June 1st, 1911, and the influence of the improved and accelerated method of transit became manifest immediately. On the day the first regular train steamed over the Kao Plung Pass every caravan running over the ridge to the Plain of Phrae was withdrawn, leaving the field entirely to the railway. High-road transportation was unable to withstand the competition of the new rival. Whereas the caravans charged, on the average, 1s. 10·4d. per ton-mile, the railway was prepared to handle the traffic at a rate from 90 to 99 per cent. cheaper. Under these conditions some idea of the revolution in existing trade relations wrought by the appearance of the railway may be gathered. In fact, it was so complete that the natives in the interior could not grasp its import. It introduced the possibility of their receiving and sending goods of a bulky nature and of inferior value, such as never had been possible before, owing to the high rates charged by the caravans. Naturally, under these conditions, the railway had to embark upon a plan of campaign to demonstrate the advantages it offered. During the month the line was opened the traffic, passenger and freight, which passed through Meh Puak station aggregated £265. Ten months later the traffic had grown to £3,784 for the month.

To the Frontier.

The Government, however, appreciated the fact that the utmost benefit could not accrue from the railway facilities until the line reached the northern frontier at Chiengsen. Meh Puak serves only one field of consumption — the Plain of Phrae, but there are several other places where trade can be created between Meh Puak and the frontier, such as Muang Ngao, Chiengrai, etc., which points at present are dependent exclusively upon the costly caravan service. Under these circumstances the Government decided to drive the line to the frontier with all speed, touching all the possible trade centres en route. On January 26th, 1912, the royal Railway Department was instructed to commence the extension of 138 miles to Chiengmai, £991,700 being allotted for this purpose. Work upon this section is now in active progress.

The Director-General.

Owing to the remarkable growth of the railway system, the Government, in July, 1909, created a subsidiary department for the construction of all the railways in the Siamese Dominions in the Malay Peninsula, which are being built on the metre gauge, as explained previously. The two departments, however, are under one Director-General of Railways, which office is filled by Mr. L. Weiler. It is due to the activity and enterprise of this engineer-in-chief, who has been well supported by His Excellency Chow Phya Wongsa Nuprabhadh, Minister of Communications, that the railway expansion of Siam has been so rapid, and that all new works are prosecuted so vigorously, and I am indebted to his courtesy for the information contained in this description of the railway system of the country.

Bangkok to Penang —2½ days.

The second railway department is engaged upon a project as comprehensive and extensive as that being consummated on the standard guage in other parts of the country. It comprises the continuation of the line from Petchaburi, in an almost due southerly direction, to Bandon, and thence to Tung Sawn. This will be an important junction, with one branch running westwards to Trang terminus, and the eastern line extending to the Kelantan boundary, via Patalung, Singora Junction, Yaleh, and Rangeh. At the frontier

BUILDING A TUNNEL ON THE MOUNTAIN SECTION OF THE NORTHERN RAILWAY OF SIAM.

there will be connection ultimately with the railway system of the Federated Malay States. The direct line from Petchaburi to the Kelantan boundary will be some 606 miles in length, while that from Petchaburi to Trang is estimated to be 425 miles. Trang will be the port for Penang, which is about 130 miles distant by sea. It is anticipated that the train journey from Bangkok to Trang will occupy about eighteen hours, and then, with a 10-knot boat from Trang to Penang, it will be possible to complete the whole journey in about thirty hours. Even if two and a half days be allowed for the journey between Bangkok and Penang this will represent a decided acceleration, since at present the journey by sea occupies from six to eight days.

Mails and Mines.

The railway, in addition to constituting an important direct link of communication, will serve a population of over 1,250,000 scattered throughout the Siamese Dominions in the Malay Peninsula, and will open up a vast tract of country eminently adapted to cattle raising, paddy culture, rubber planting, and other tropical agricultural pursuits. Also, it will assist the tin-mining, which is now carried on in many places, as well as provide facilities for working the gold, wolfram, coal, and other mineral deposits which are said to exist throughout this territory. It will affect communication with Europe very materially, inasmuch as it will enable the mail service to be accelerated, via Trang and Penang, by three or four days. The benefits which are certain to accrue from the linking together of the Siamese and Federated Malay States railways, too, cannot be estimated.

The Siamese Government has not failed to realise the economic and industrial significance of this southern railway, and is resolved to complete it with all possible speed to Trang. Construction southwards from Petchaburi was commenced in September, 1909, and has been pushed forward vigorously ever since.

Further Extensions.

The grade is being attacked from three points simultaneously — the existing railhead, Singora, and Trang. It is already available for traffic as far as Ban Hua Hin, 39 miles from Petchaburi, and it is anticipated that Trang will be in railway touch with Bangkok by the year 1915. It is being built departmentally under the direction of the Minister of Ways and Communications, and it is expected that the total cost of the undertaking will amount to £3,383,500. The provincial authorities in the territory served are fully alive to the important part the railway is destined to play in the development of the Siamese peninsula, and throughout this country great activity is being displayed in the building of roads to connect outlying towns with the railway. They are being built upon substantial lines, with bridges of heavy construction, so as to be available for motor traffic.

Although the State is carrying out the works of first magnitude, private enterprise is not stifled. Concessions for narrow gauge lines have been, and are, granted to private interests, mostly for connecting isolated districts with the existing railway, or to serve as feeders. Up to date 66¼ miles of private lines are in operation.

Rapid Developments.

The rapid and complete growth of the railway in such a country as Siam is remarkable. Seeing that twenty years ago the country possessed only 12½ miles of line, the construction of 693 miles in two decades, and bearing in mind the local conditions, is astonishing. Of this total 639 miles belong to, and are operated by, the Government, which has a further 520 miles in course of construction, and over 600 additional miles sanctioned. From the point of view of the State the railways are proving a first-class investment. During the Siamese year 130 (April, 1911–12)

the net profit, after making a deduction for the Renovation Fund—renewals, etc. —amounted to £152,801 15s. 2d., corresponding to 4·26 per cent. upon the capital outlay of £3,584,583 6s. 8d.

The railway is substantially constructed, the standard being somewhat heavier upon the broad than upon the narrow gauge. The permanent way is ballasted with broken stone and gravel, with the rails laid upon sawn wooden sleepers. The stations, in the first instance, are of light wooden construction, except in the case of important points, where permanent buildings in masonry are provided. As the traffic develops, however, the intermediate stations are overhauled and improved. A siding is provided, this accommodation being extended according to the exigencies of increasing traffic. The gangers are provided with permanent-way huts, placed at frequent intervals, while a telegraph line and signalling facilities are installed. While timber has been utilised for the smaller bridges, such are only temporary, being replaced in steel as soon as possible.

A SINGLE SPAN BRIDGE OVER THE KLONG THA LAW, ON THE NORTHERN RAILWAY, SIAM
The span is 263 feet. On the river are some of the quaint craft by which transportation was effected before the railway was built.

Culverts are carried out in concrete, while ferro-concrete is used for pipe-culverts of 24 inches diameter.

Owing to the substantial construction of the embankments and cuttings, little damage is inflicted upon the permanent way by the torrential rains and floods, which are experienced at certain periods of the year. On the mountain section between Pang Tong Phung and Meh Puak traffic was interrupted for three days only during the year 130 by slips in the deep

cuttings. On the Southern Line there was an interruption of twelve days' duration in the same year, as the rains caused heavy damage to the banks and bridges between Rathburi and Petchaburi.

The natives appreciate the provision of the steel highway in a manner differing from that intended. It is far easier for walking along than the primitive trails and up-country high-roads, and in many cases offers a short cut. Accordingly they are disposed to make avail of the track, but to their own danger, as events from time to time have proved. One or two pedestrians have been caught unawares, especially during stormy weather, by trains approaching from behind, and have been killed. At the same time, one scarcely would consider the metals an ideal couch for a nap. Yet such is the case. More than one wanderer has been run over while asleep. This tendency, however, is not confined to strangers or trespassers, because only a short while ago the driver of an up-country train on the Northern Line while making speed suddenly felt a disconcerting jolt. He pulled up and went back to ascertain the cause of the unusual vibration. To his surprise, he found that he had run over and killed a permanent-way coolie while fast asleep with his head pillowed on the rail.

A TYPICAL UP-COUNTRY STATION IN SIAM.
Showing a water tank, pumping plant and the administration buildings.

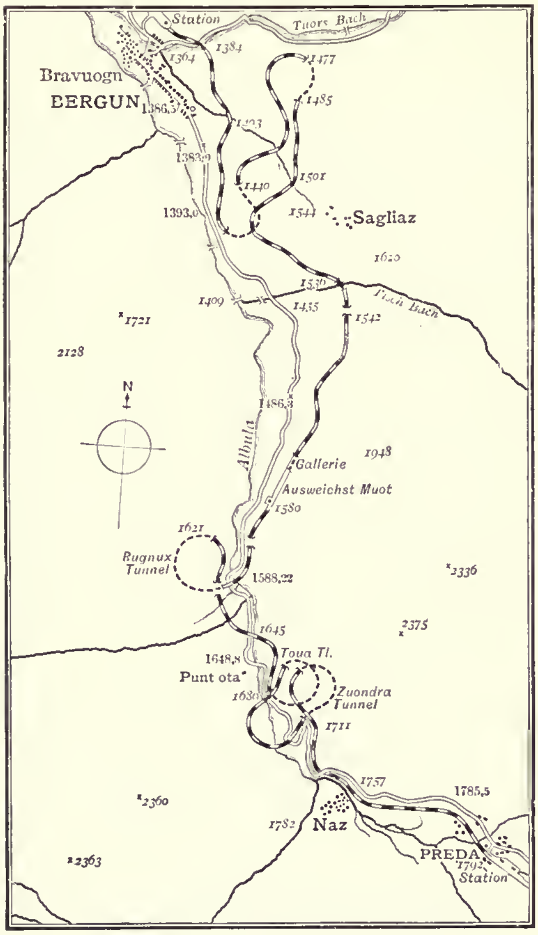
THE ALBULA VIADUCT. *Photograph by A. G. Wehrli, Zurich.*

The Most Wonderful Narrow Gauge Railway in the World

HOW THE RHAETIAN RAILWAY CONQUERED THE ALPS

AS a rule, the average individual regards and uses the railway purely as a means of passing from here to there in the shortest possible time and with the minimum of personal inconvenience, either in the interests of business or pleasure. But there is one railway which is patronised by the traveller because it differs in every respect from anything else over which he has journeyed; because it is a maze of twists and turns, of lofty bridges and spidery viaducts, of wonderful tunnels and devices for dodging the dreaded avalanche. This is the system comprised under the official title of the Rhaetian Railway. No visitor to the Swiss Highlands of the Grisons omits to take a trip over this line. Why? Certainly the panoramas unfolded from the carriage windows would be difficult to excel for variety, sublimity, and beauty, even in the Playground of Europe. And yet it is not Nature unadorned which is so much appreciated as man's triumph over Nature.

The Grisons probably constitute the most tumbled corner of a wonderfully mountainous country. The clusters of peaks, crowned by magnificent glaciers, tower to 13,124 feet, and are broken up by over 150 valleys, mere rifts through which savage torrents and boisterous waterfalls tumble and foam. Again, the altitude of these valleys varies startlingly. The Rhine Valley, near Chur, lies at the comparatively low level of 1,969 feet above the North Sea, but the Avers Valley, the highest depression in Europe in which agricultural activity may be seen, and where there are apparently sleepy but busy villages, is 5,920 feet higher among the clouds.



SKETCH MAP OF THE RHAETIAN RAILWAY BETWEEN BERGUN AND PREDA.

It was when the railway era dawned that the awakening of the Grisons came. The introduction of George Stephenson's invention into Switzerland prompted many schemes for opening up the Rhaetian Alps. Among these was an idea for running a main steelway through the Canton to carry the bulk of the traffic between north and south; but, the St. Gotthard tunnel and railway obtaining the greater support, the trans-Rhaetian was forced into the background.

Although the Canton of the Grisons was denied the great trunk highway, those interested in railway development did not despair. They determined to carry out a comprehensive inter-cantonal railway building programme. Such a move was vital to the interests of the Grisons, and it was mainly through the untiring efforts of Herr W. J. Holsboer, the founder of the world-famous health resort of Davos, that the present railway system intersecting the Canton was laid.

Yet many years passed before Herr Holsboer's dreams came within measurable distance of fulfilment. True, a line was built from Rorschäch to Chur, through the Grisons territory, but the true railway development of the Canton dates from the year 1888, when the construction of the Landquart and Davos Railway was commenced. When this scheme was taken in hand the question of gauge arose. Certain interests advocated the British standard gauge to bring the line into harmony with the Federal system, and to facilitate the interchange of traffic, but the engineers pointed out that such a procedure, owing to the physical characteristics of the country to be threaded, would enhance the cost of construction to a prohibitive figure. On the other hand, a substantial line of 1 metre gauge (3·28 feet) could be built just as solidly at a much cheaper figure, and produce results equally as remunerative. The cold facts and figures of the engineers carried the day; the narrow gauge was adopted. Only one mistake

was made. This was the introduction of a gradient rising 1 in 22·2, between Landquart and Klosters. This stretch was opened on October 9th, 1889, and as it is worked by adhesion purely and simply, it constitutes a remarkable piece of road.

This section, though comparatively short —20½ miles—serves to convey some idea of the technical difficulties involved in meshing the Grisons in a net of steel. Klosters is 2,187 feet above Landquart, so that the length of maximum grade is heavy, especially upon the 7 miles between Kublis and Landquart. The mountain flanks, torn and humped, demanded heavy bridging and tunnelling, as well as big cuts and side-hill excavation. This initial scheme was completed in 1890, the railway being opened for traffic to Davos on June 21st, the 31 miles having cost £340,000.

Masonry Bridges.

In 1894 the Landquart and Davos Narrow Gauge Railway Company, which had been incorporated to complete this undertaking, and had secured concessions to continue to Chur and Thusis, was reorganised under the title of the Rhaetian Railways, and the extensions were taken in hand without delay. The experience gained in connection with the first section proved of inestimable value in drawing up the specifications for all future constructional work. As it was realised that the maximum gradient of 1 in 22·2 was far too heavy for economical working by adhesion, and the introduction of the rack-rail being regarded with disfavour, it was decided to ease the heaviest gradient upon future lines to 1 in 28·5. This decision enhanced the extent of the development work in the tight corners, but it was conceded that a little extra mileage in order to preserve the grade would be preferable to excessively steep banks and limited train loads. At the same time it was decided, from æsthetical considerations, to carry out all bridges and viaducts in masonry in preference to steel. The latter certainly was the cheaper medium, but the stone was deemed preferable as it would reduce the marring of the landscape to the minimum. Accordingly, except in very few instances, stonework has been employed exclusively for such structures.

Although Davos was the terminus of the initial enterprise, it was decided to extend the line southwestwards to Filisur. This link is only about 12 miles in length, but it proved somewhat costly—£217,600, or approximately £18,133 per mile. This arose from the heavy bridging and tunnelling which was found unavoidable in order to keep within the maximum grade of 1 in 28·5 and minimum curvature of 395 feet radius which were established in such a cramped valley as that of the Landwasser. The Züge, as the gorge is called, is very wild and rugged, and the engineers were forced to swing from side to side over the foaming waterway in order to take advantage of a convenient location. A considerable proportion of tunnelling was preferred to an open-air alignment, in order to escape the ravages of the avalanche. During the early spring the snow movements are terrific, and on several occasions serious delays have arisen from the line becoming blocked by slides. On the post road, which practically parallels the railway, and which is swept just as severely, many fatal accidents have occurred from this cause.

The Wiesen Viaduct.

The bridging compels attention owing to its bold character. Near Brombenz the railway swings over both the river and the post road by means of a viaduct 147·6 feet in length, and 75·4 feet in height. But the most striking work of this character is the Wiesen Viaduct, spanning the Landwasser at a height of 289 feet. This is a magnificent work, 689 feet from end to end, comprising six openings, each of 66 feet, and a parabolic arch over the gorge, 180 feet clear in the span, thereby rendering it one of the largest stone bridges in Europe.

The railway from Landquart to Chur,

AN AMAZING EXAMPLE OF ENGINEERING

The line enters the upper tunnel portal at right and makes a spiral turn in the mountain to emerge from the lower windings gains the opposite

Photograph by A. G. Wehrli, Kilchburg, Zurich.

ON THE RHAETIAN RAILWAY.

entrance. It then describes a loop to double upon and under the higher level, and continuing its wonderful side of the ravine.

and thence on to Thusis, the concessions for which had been obtained by the original company, were completed. Owing to the easier configuration of the land this section of 25·8 miles did not offer any great difficulties to the engineer, and was completed for £280,000. The minimum radius of 328 feet for curves which had been adopted on the first line was followed, but the maximum grade was kept down to 1 in 40.

Extension to St. Moritz.

When Thusis was reached it was decided to push on to St. Moritz and Pontresina, thus bringing the original idea—namely, to provide a narrow gauge steel highway through the Canton to link up with the lines running to Italian points—within easy distance of consummation. The Confederation assisted this enterprise by the grant of a subvention, because, the benefits accruing to the community by the provision of this alpine railway to Italy being far-reaching, such State assistance was considered advisable in the public interests.

The Summit Tunnel.

The engineers pointed out that the connection of St. Moritz to Thusis by 38·34 miles of railway would be exceedingly costly, even on the narrow gauge, and that it would bristle with teasing technical problems. The plotters proposed to follow the only available pathway. This was the tortuous rift through which flows the Albula River, and after which, indeed, this line is named. The greatest and most trying piece of work would be the boring of the Summit Tunnel, some 4 miles in length, which could not be avoided. Seeing that a tunnel of this magnitude would not be undertaken lightly on a standard gauge trunk road, it is not surprising that the project was discussed at great length before a metal was laid a yard beyond Thusis. However, minute investigation of the territory to be traversed failed to reveal a practicable alternative route, and so the project, including the tunnel, was attacked boldly. It was found impossible to secure an easier maximum gradient than 1 in 28·6, and although the minimum curvature was set down at 395 feet radius, the engineers were forced to describe sharper curves of 328 feet radius at one or two points, owing to lack of space in which to complete the easier loop.

The Albula Railway is essentially a mountain railway. It commences its meandering up-hill toil directly it leaves the station at Thusis, crawling at 20 miles an hour over the stiffest banks of 1 in 40, which prevail to Filisur. The tree-clad forest slopes tumble abruptly into the gorge forming the river's passage, and at places the rift narrows down to such a degree that the train is forced from one cliff to the other, while, where the declivities are so steep as to preclude the blasting of a shelf or the widening of a ledge of rock to carry the metals, the line is driven through the shoulders and humps. The tunnels individually are of short length, but in the total of 38·34 miles they represent no less than 33,350 feet exclusive of the great Albula Tunnel. Owing to the soft character of the rock, as well as the percolation of water, the cost of tunnel construction was inflated by the necessity of having to make recourse to lining, it being found possible to leave only 7,892 feet of tunnelling in the condition left by the rock-borers' tools. The result was that, taken on the whole, these small tunnels cost approximately £5 per lineal foot to drive.

The Solis Bridge.

The bridging is no less impressive. The Solis Ravine is one of the most wildly picturesque canyons in the country, and the single arch bridge which carries the post road over the torrent below is one of the most popularly favoured spots in the Grisons. This bridge, which has commanded such widespread attention from its daring character, has been eclipsed by the structure which carries the railway across the rift. The main arch, of 138 feet

clear span, springs from either cliff face, wherein the abutments have been bedded, bringing the metals 292 feet—3 feet higher than the Wiesen Bridge on the Davos line —above the water.

Approaching Filisur the Albula valley becomes more and more contracted. While the torrent thunders and lashes along its floor, the railway, ever ascending, hugs a level high up on the mountain face, to offer many fascinating evidences of engineering resource. Among these is the Schmitten-Tobel masonry viaduct, 449 feet long, by 115 feet in height, carried upon seven arches, each of 49 feet span in the clear. Then the railway dives through a short tunnel to emerge from a precipitous cliff upon the Landwasser Viaduct. The sudden emergence from the darkness of the tunnel apparently into mid-air is startling, as this viaduct with six spans of 66 feet, giving a total length of 426 feet by 213 feet in height, provokes a curious sensation, which is by no means alleviated upon observing that it is set upon a curve of 328 feet radius, the minimum on the railway. The situation is extremely wild, and conveys a stirring impression of the rugged country threaded by this railway. Although the viaduct occurs at a point where the line rises 1 in 40, as a compensation to the extremely sharp curve the bank is flattened to 1 in 50 over the viaduct.

The second section of the Albula Railway extends from Filisur to Bevers, 19½ miles. This is the most interesting part of the whole system, inasmuch as it not only includes the Albula Tunnel but also offers some wonderful examples of engineering prowess, more particularly between Bergun and Preda. Furthermore, the gradient becomes heavier, being almost a continuous climb at 1 in 28·6 from Filisur to Preda, at the mouth of the Albula Tunnel, so that the travelling speed of the train up the banks is restricted to about 11 miles per hour.

As the crow flies Preda is about 7 miles from Filisur, while the former lies 2,324 feet

THE LANDWASSER VIADUCT.
213 feet in height, 426 feet long, set on a curve of 328 feet radius and a gradient of 1 in 40.

above the latter. As it was impossible to overcome this heavy difference in levels, by means of the maximum gradient, in a direct line, the railway plotters had to resort to heavy development work in the

Photograph by A. G. Wehrli, Kilchberg, Zurich.

THE WIESEN VIADUCT, 689 FEET LONG, OVER THE LANDWASSER RIVER.

The central arch has a clear span of 180 feet, and the metals are 289 feet above the waterway.

form of loops, spiral tunnels, and so forth, thereby increasing the distance by the railway to 11 miles between the two points. The first evidence of this ingenuity is offered by the Griefenstein spiral, which lifts the line a matter of 121 feet. This comprises a big loop, 3,937 feet in length, with a spiral tunnel 2,290 feet long. By this means the line gains and hugs a precipitous slope, 492 feet above the floor of the valley. As the railway here is exposed to rock slides, it is protected against sudden descents of loose boulders and debris by massive masonry walls. In fact, at various places along the railway, where the flanks sheer up abruptly from the permanent way, straggling ramparts of stone, resembling the crumbling fragments of castles and fortifications of a long distant past may be descried high above. These are the defences against the snow and rock slides which, but for such precautionary measures, would menace the safety of the slender link of communication at those periods of the year when such movements are to be expected. Indeed, when the line first was built between Stuls and Bergun it followed an open alignment after emerging from the Bergunstein Tunnel, but became imperilled by a dangerous landslip. Fearing that the track might be overwhelmed and destroyed one day, precipitating possibly a terrible disaster, the railway engineers suggested carrying it farther into the mountain side through a tunnel. The railway authorities, appreciating the suggestion, sanctioned the deviation, and

Photograph by A. G. Wehrli, Kilchburg, Zurich.

THE SOLIS VIADUCT.

Spanning the Solis Ravine, through which runs the Albula River, 292 feet below.

thereupon the Glatscheras Tunnel, 1,090 feet long, was driven, so as to compass the danger spot.

A Tortuous Line.

From Bergun to Preda direct, along the valley, is a matter of only 4 miles, but by rail it is 7·8 miles, and in this distance the train climbs 1,365 feet. Owing to the startling twists and turns of the train in ascending the valley, it is difficult for a passenger to retain his bearings, as he appears to box the compass during his journey. The wonderfully clever alignment and development works may be grasped more comprehensively by a perusal of the diagram on p. 298 of the railway between Bergun and Preda. Leaving Bergun station the railway, after crossing the Tuors Bach, runs almost due south for some distance, until by means of a huge loop, part of which is in the God Tunnel, it is swung northwards until it almost regains the Tuors Bach. The introduction of another loop, also partly in a tunnel, serves to reverse it once more, and it runs southwards again, crossing itself above the God Tunnel, to Muot Siding. Just before the latter point is reached the railway plunges through what seems to be a tunnel perched on a crag, with openings on the western side, through which glimpses of the valley may be seen. This is the Chanelletta avalanche gallery. For a distance of 383·76 feet the track has been enclosed in the masonry counterpart of a timber snowshed. At this spot the location is so exposed to such tremendous snow slides that nothing short of a masonry structure could be expected to withstand their onslaughts.

An Unexpected Spring.

After leaving Muot Siding the railway swings across the Albula River to describe almost a complete circle in the Rugnux Tunnel, 2,235·5 feet from end to end. The driving of this burrow perplexed the builders sorely. The unexpected was encountered in the form of a spring of cold water, the temperature of which was only 39 degrees Fahr., and it played havoc with the health and endurance of the navvies. This inundation assumed such significance that many months elapsed before it was mastered sufficiently to enable the borers to resume their task.

Leaving the mountain's heart, the railway bends somewhat to the south, recrosses the Albula, and thence reveals the most wonderful piece of work on the whole system. This is the double spiral tunnel. The railway suddenly dives into the mountain flank, practically making a circle, which for 1,611 feet lies in the Toua Tunnel. When the line has regained the point where it enters the mountain, but some distance above, it darts across the river and completes a large semi-circular loop on the opposite bank. Recrossing the river it disappears again into the mountain through the Zuondra Tunnel for 1,576 feet, wherein it makes another corkscrew ascent, The most curious feature is that this second tunnel partially overlaps the Toua Tunnel, though some distance above it. Some idea of the extent to which the difference in level is overcome by this unique work may be gathered from the fact that in this series of loops the metals are lifted over 160 feet in less than $1\frac{1}{2}$ miles.

The Albula Tunnel.

The crowning achievement of this railway, however, is the Albula Tunnel, the northern portal of which faces Preda station. It burrows at a depth of 2,992 feet beneath the summit of the Giumels mountain for a distance of 19,242 feet, and easily ranks as the longest narrow gauge railway tunnel in the world. The bore was commenced in October, 1898. But the rock-hogs had not penetrated very far into the heart of the crest before troubles and difficulties innumerable were encountered. The headings ran through soft stone and dolomite sand, and so many underground springs were tapped that the workings were in danger of being flooded. The navvies

toiled valiantly in the effort to reach the denser rock beyond, but the water got the upper hand. For fifteen months advance on the northern face was interrupted, the engineers striving night and main to devise some means of coping with this enemy. At last they succeeded, and the navvies got beyond the danger spots. When the solid granite was reached, the ponderous Brandt rock drills, which make short work of the densest material, were brought up. A battery of three of these implements were kept chugging upon the rock face at either end, and by their aid the rock-hogs succeeded in notching an average daily advance of 19·3 lineal feet, and they maintained it to such excellent effect that on May 29th, 1902, the two headings, driven from either side of the mountain, met. The crest was conquered. In this self-same year the tunnel-builders accomplished a magnificent achievement by finishing 9,840 feet of the bore. Owing to the geological formation through which the tunnel was driven, heavy lining had to be adopted, though the granite stretch remains as the chisels left it. By the time the work was finished £282,000 had been spent—£14 12s. 8d. per lineal foot.

5,998 feet above the Sea.

The railway enters the tunnel from Preda at 1 in 100 to the centre, which marks the summit level of the Albula Railway, 5,998 feet above sea level. Thence it descends towards Spinas at 1 in 500. The train occupies about ten minutes in passing through the bore, in which the temperature is about 61 degrees Fahr. After leaving Spinas the line falls steadily towards Bevers, about 1½ miles beyond. Thence the third section of the railway extends to Samaden, where it bifurcates, one branch running to St. Moritz, and the other to Pontresina.

From Pontresina the Bernina Electric Railway runs to Tirano, a distance of about 37½ miles. This railway is likewise of metre gauge, with a summit level of 5,369 feet above sea level in the Bernina Pass. As it traverses very broken country the differences in levels are often very abrupt. On the north side the climb of 1,071 feet has to be overcome within a distance of 13¾ miles, while on the south side it falls 4,760 feet in the 23¾ miles between the Bernina Hospice and Tirano. Under such circumstances the grades on this side are very severe, the maximum being 1 in 14·28, while the curves are as sharp as 147·6 feet radius. Here and there the development works are of an imposing character in order to overcome a sudden falling away of the ground, the curve at Brusio being especially noticeable.

How the Avalanche is Avoided.

The perils of the avalanche at exposed points on steep mountain declivities were not ignored, but were avoided by driving short tunnels, of which there are thirteen, the longest being the Charnadura of 1,666 feet and the Grum of 714 feet respectively.

Braking Arrangements.

Three-phase current of 7,000 volts at 50 cycles per second is supplied from the Brusio electric generating station. It is transmitted at 25,000 volts over high tension conductors to four sub-stations distributed along the railway, where it is transformed into direct current, and stepped down to 750 volts, at which pressure it is fed to the trains. Owing to the severity of the gradients the trains are fitted with four braking systems, including the Hardy air brake, and electro-magnetic brake acting upon the rails. Despite the constructional difficulties encountered the railway was completed in four years, being opened for traffic during the summer of 1910.

Locomotives.

The Rhaetian Railway is contemplating conversion from steam to electrical working. The locomotive equipment at present used varies from Mallet duplex (2–4–4–0) and 0–4–4–0 tanks with running weights varying from 36·9 to 43·6 tons, two cylinder four coupled compounds, and 2–8–0 engines with tenders, the latter

having superheaters and weighing 47 tons ready for the road.

Although the Rhaetian Railway at present has a mileage of 123·7 miles open to traffic, extensions are in course of construction. One of these is that from Reichenau to Ilanz, where a piece of development work compares with anything to be found anywhere else on the system. This is where the line runs through the Flims Landslip in the Vorder-Rhine Valley. The side of this depression is very precipitous but unstable, inasmuch as it is composed of rubble and debris brought down and broken up by the great slide, while further detritus is piled up by subsequent falls of loose material. To save the line from burial the engineers have either introduced a trench between the grade and the cliff, into which the rocks may drop, or have struck out boldly to reclaim the land which has been eaten away by the river itself by throwing up huge dykes to force the water back and to preserve the permanent way from erosion.

One might be disposed to include this railway in the category of "toy railways," a term often extended to those lines of less than the British standard gauge. But it is not a toy railway by any means. It is built just as massively and as substantially as its bigger rivals, and to-day is reckoned among the important lines upon the European continent. This contention is supported by the fact that it is admitted into the European railway time-table conferences, and is the only system of its gauge to receive such recognition.

Photograph by Charles Meisser, Zurich.

THE CHANELLETTA GALLERY.

It is 383¾ feet long, and is massively built in masonry to protect the line from avalanches.

EXTERIOR OF THE CABIN CONTAINING THE 360-LEVER MACHINE CONTROLLING ALL TRAIN MOVEMENTS TO AND FROM THE UPPER LEVEL.

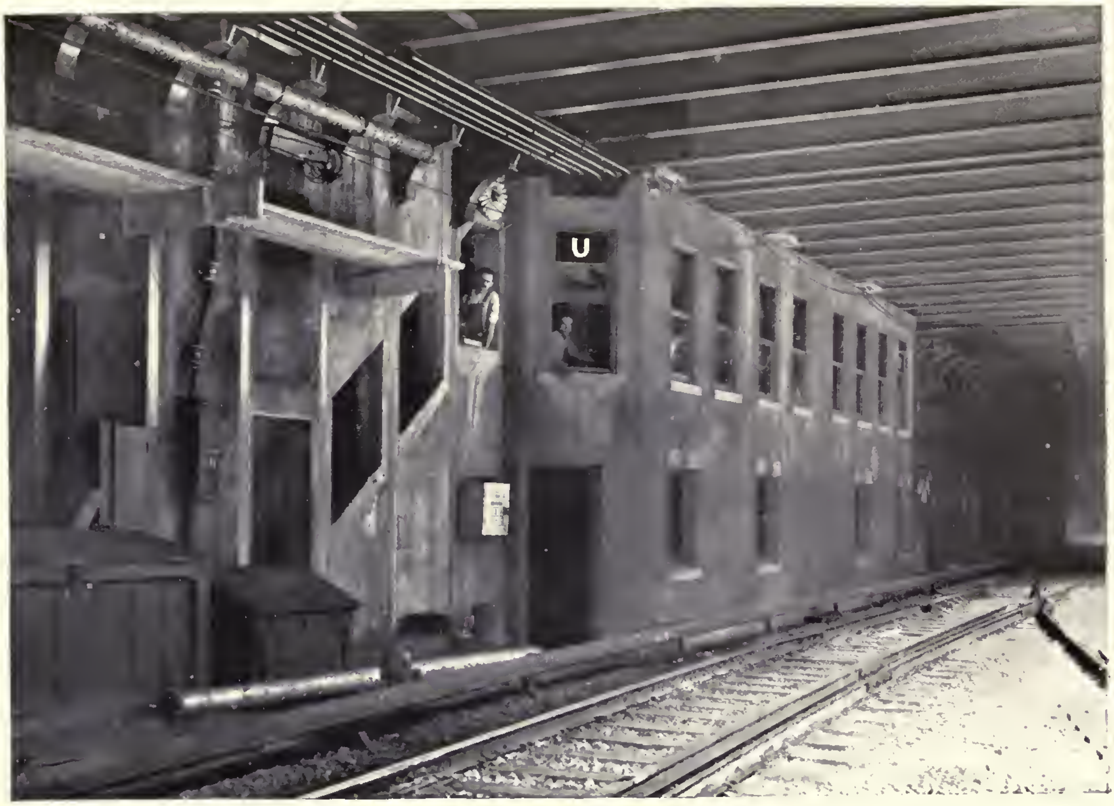
Signalling Without Seeing the Trains

ONE OF THE MOST MARVELLOUS SIGNALLING INSTALLATIONS IN THE WORLD

UNTIL the Pennsylvania Railroad laid tubes under the Hudson River so as to carry its metals from the New Jersey shore into New York City, the only trunk system which had its terminus in the capital of the Empire State was the New York Central and Hudson River Railroad. This strategical advantage was secured by entering the city from the north, thereby avoiding the wide, busy waterways which wash the projecting spit of rock known as Manhattan Island.

The builders of this railway plotted their line and terminus facilities for their day; they gave no thought to the exigencies of the future. Three times the Grand Central station, as this terminus is called, has had to be built in order to keep pace with the growth of traffic. The present structure was completed in 1912, and to-day ranks as one of the largest terminals in the world. When this work was taken in hand it became necessary to increase the number of roads so as to accommodate the traffic. Land being costly, they could not be laid upon the surface, as in the previous station;

nor could they all be disposed upon one level, except at a prohibitive outlay. Accordingly it was decided to distribute the sets of rails upon two levels, in order to meet the terminal situation most effectively. The upper level, which is 34 feet below the street, carries twenty-nine tracks, while the lower level, 55 feet beneath the public thoroughfares, has twenty-two roads. The whole of these fifty-one tracks are provided for the convenience of passengers, mail and baggage. In addition, there are sixty-two other pairs of rails for the storage of electric locomotives and trains. Previously the trains had to be backed out of the station, and hauled a distance of five miles to Mott Haven Junction yards, where sidings were provided for their accommodation. Such a necessity not only represented a heavy aggregate of unremunerative haulage, but also served to congest traffic, inasmuch as the whole of the business has to pass in and out of New York over four roads—two up and two down. This bottleneck affected the capacity of the terminus very severely, so that by the time the new works were taken in hand not another train could be squeezed into the daily service.



EXTERIOR OF ONE OF THE UNDERGROUND INTERLOCKING STATIONS.
Above this cabin on the street level is a 12-floor skyscraper.

By providing the terminal station with platforms at two different depths below the street level, the railway solved an abstruse problem very completely. The upper level is roofed over and covered with streets and huge buildings. Altogether there are 79 acres of sidings and lines provided beneath the imposing hotels, boarding-houses, offices and stately thoroughfares surrounding the Grand Central station. As may be realised, owing to this system, the lines are completely hemmed in, especially those on the lower level, which are flanked on either side

by massive steel columns supporting, not only the tracks of the upper level, but also the various buildings above which vary from eight to twenty-three stories in height.

Under such conditions the task of laying out a complete signalling system so as to guard the 113 different roads was intricate and complex, while the situation and construction of the interlocking stations was even more complicated, inasmuch as the conditions rendered it impossible to see the trains arriving or departing from the main line connections.

The Largest Interlocking Station.

The solution of the signalling problem forms one of the most outstanding features of the Grand Central station, while, undoubtedly, it constitutes one of the most marvellous installations among the railways of the world. The all-electric system was adopted as being that which would meet all requirements most completely and efficiently, and this is the largest lay-out in the world to be operated in this manner. Moreover, the interlocking station on the lower level is one of the largest which ever has been built, as it carries 400 levers, each of which operates a point or a signal. Altogether, there are five interlocking stations manipulating 238 sets of points and crossings, and 570 signals, to control the 1,200 train movements which are made during every twenty-four hours.

The Tracks.

In order to grasp the full significance of the signalling arrangements it is necessary to gain some idea of the disposition of the tracks between the bottleneck and the station. All the various lines ramifying in all directions converge into the two up and two down roads at a point about 5 miles outside the terminus. These four tracks run partly through tunnel and over elevated structures for about $3\frac{1}{2}$ miles. At this point they spread out like a double fan to form the upper and lower levels respectively. The first-named handles the whole of the long-distance traffic, while the last-named is devoted to the suburban and local business. At this point the four roads are resolved into ten tracks, four connecting with the lower, and six with the upper, level, and here is the first, or A, interlocking station. About three-quarters of a mile nearer the terminus on the lower level is the B interlocking station, which contains the 400 levers. This station controls all the movements on the lower level, since here the four tracks are multiplied into twenty-two roads. Above this box, on the upper level, is the C cabin, which controls all the movements on the upper level over the passenger, mail, and baggage tracks. About 150 feet beyond C and on the same level is the fourth, or D cabin, whereby all the storage trains are handled, while about a quarter of a mile beyond signalling-box B, on the lower level, is the fifth, or E, interlocking station.

The local trains, instead of coming to dead ends as in the ordinary terminus, swing round a big oval loop, so that, after discharging their passengers, they can, if required, pass round to the storage yard until their next turn of duty arrives. The consequence is that there is no congestion in the station; the bottleneck is left free for the handling of remunerative traffic.

The Director.

As the whole of the cabins are placed underground, and the range of vision is limited very severely, a signalling system differing from that generally practised had to be adopted. In each cabin there is a director or general manager of the train or interlocking movements. He has nothing to do with the handling of the levers. His sole duty is to receive and to pass on the trains. His desk is provided with a telephone and telegraph, while in front of him are mounted diagrams showing all the roads, points, crossings, station platforms and station tracks under his jurisdiction. Facing him is a chart, on the ground-glass face of which is indicated a facsimile of the tracks. Within the case, and behind the ground-

THE INTERIOR OF THE LOWER LEVEL INTERLOCKING STATION, SHOWING LEVER FRAME.
This machine, 55 feet underground, contains 400 levers, and the roads which it controls cover 23 acres of ground. The lever-men merely pull the levers called out by the director.

glass, are small electric lights, indicating all the points and crossings. As a train passes over a set of points the corresponding light on the chart is extinguished, and is not relighted until the train has passed over the crossing on to the succeeding one. Thus the director, by glancing at his chart, can detect instantly the precise position of the trains upon the roads under his control. The points and signals are interlocked, so that no error on the part of the operator can set a signal or points in a conflicting manner. Both must agree, thereby assuring the safety of the train. The electric lights on the chart are controlled automatically by the train itself through relays operated by alternating current track circuits.

The ordinary type of semaphore signal is utilised, and at danger occupies the normal horizontal position. When the controlling lever in the cabin is moved, the small electric motor whereby the semaphore is actuated moves the arm upward to indicate "line clear." When the lever is pushed back, the semaphore drops by gravity to the danger position. This arrangement has the additional advantage that, should any failure occur in the electric system, the arm must fall to the danger position, notwithstanding that the line may be clear.

The signal-operating system is entirely in the hands of the director. Notification of an incoming train is given first by tele-

graph from the mouth of the bottleneck, 5 miles distant. The director of tower A prepares to receive it, and he warns the director of box B or C, according to whether it is for the upper or for the lower level, of its approach. We will suppose that the train is for the lower level. The director of cabin B, although apprised of the approach of the train, does not know on which of the six tracks the director at A will turn it. Seeing that the train is travelling probably at 30 miles an hour, the intimation must be of the briefest and quickest character. There is no time for telegraphing. When the director at A has decided the road for the train he presses a small electric button on his desk. Instantly a light on the track chart in box B lights up, indicating the track along which the train is coming. The director of the latter immediately

THE SIGNALLING DIRECTOR OR GENERAL MANAGER OF THE BOX, 55 FEET BELOW THE STREET LEVEL.

Showing telegraph and telephone, together with the illuminated track diagram. He calls out the numbers of the levers that are to be moved.

presses a similar button which communicates to the director at A that he, the director at B, has received and understands the signal.

An additional signal also is given to the director in B box, from a point $1\frac{1}{2}$ miles distant from the terminus, by the train itself, through the automatically operating track circuit devices.

To carry the train through his territory the director at B box sets his road. He calls out a number, or numbers, corresponding to the lever, or levers, which he desires to be moved to carry the train over certain tracks. The "lever-men," as the operators are called, at once move the levers to set the points and signals, a small electric light showing above those levers which are moved. These men have nothing to do but to move the levers indicated by the director. He is the pulse of the cabin: the lever-men merely pace up and down before the "piano box," as they call the frame, moving the levers at the director's bidding. As the director receives notification of a train, he records it upon the official form on his desk, which is a permanent record of the movements of a train through the section, and this is filed by the department. Thus, should an accident occur from any cause, it is not a difficult matter to fix the responsibility.

The Lever-men.

The director's duty appears somewhat simple at first sight, but when the number of tracks under his control are borne in mind, together with the fact that possibly twenty trains are moving in both directions simultaneously through his territory, it will be seen that he must maintain a clear head and concentrate his mind upon his work. A momentary lapse, the calling out of the wrong number—and then a smash. He is guided in his work entirely by the track lights and telegraphic signals which come to and pass from him.

Another duty has to be performed by the director in box A, which, as mentioned previously, is the first in the chain. Directly he has decided upon which track to turn the incoming train, his assistant, by the aid of the telautograph, communicates to an official on the station the information at which platform such-and-such a train will arrive. This station official, being in charge of the bulletin board, receives the written order upon the machine before him. He tears off the intimation, and his assistant then chalks up the platform number on the bulletin board. Another official speaks the same news into a transmitter, and it is proclaimed from a number of electric machines scattered throughout the station, for the guidance of those who have come to meet the train.

Outgoing trains are dispatched in an equally simple manner. The tower director of the box immediately outside the station works according to the time schedule. He tells the lever-men to set so-and-so signals and points at the minute a train is scheduled to leave, and by communicating with the boxes beyond him gets a clear track to the bottleneck. No sign of the train is seen. The director merely knows that train number so-and-so is due to leave at a certain time, and clears the road for it. Should anything occur to delay the departure of the train, intimation of this fact is given by telephone to the director of the station signal cabin. Special trains are handled in a similar manner from cabin to cabin.

Outgoing Trains.

The system is complete in its thoroughness and safety. The fact that the cabin directors are given three distinct notifications of an incoming train—first, from a point 5 miles away by cabin A; secondly, from a point $1\frac{1}{2}$ miles distant, automatically by the train itself; and thirdly, by the electric light system from director to director—conduces to as smooth, steady and safe operation in semi-darkness, 55 feet below the street, as upon the surface with a clear view of the roads.

THE WRECKING CRANE AT WORK.

Clearing the steel highway. Accidents will happen in spite of the most elaborate precautions In order to restore communication in the minimum of time, wonderful and powerful cranes capable of slinging a locomotive weighing 150 [illegible]

By permission of the Bucyrus Co.

TWO 70-TON CRANES ABOUT TO SLING A CAPSIZED LOCOMOTIVE.

The "Wreckers" and their Cranes

HOW THE ROAD IS CLEARED AFTER ACCIDENTS ON THE RAILWAY

DESPITE unremitting care and the manifold precautions that are adopted to render railway travelling secure, accidents will happen. This inevitable corollary to movement over the steel highway has been responsible in turn for the creation of a special force, maintained to deal with such contingencies. This is the "breakdown gang," or, as it is called in some countries, picturesquely if not so appropriately, the "wrecking crew."

A collision or serious derailment throws the working of a railway all sixes and sevens. The streams of traffic sent flowing with marvellous precision are obstructed, and congestion and disorganisation become complete. The public, notoriously fickle and prone to grumble whenever its own convenience or interests are affected, murmurs against delays, and anathematises a system very vigorously if a mishap is permitted to block movement for a very long time, ignoring the fact that massive, powerful locomotives and heavy coaches or wagons which have capsized or piled-up are difficult, cumbersome articles to handle.

The railway manager, who receives the full brunt of public obloquy, fortunately is fully alive to the capriciousness of his patrons. So the order runs: "Clear the

line with all speed; never mind how; but clear it!" In Great Britain, where double tracking is the rule and not the exception, the full significance of this fiat may not be so apparent, since often it is possible to maintain communication by working the traffic in both directions over a single line; or possibly it can be diverted so that the delay is not very appreciable. But in those countries where transportation depends upon a single track, the tangle is disastrous, because both streams of traffic are held up completely. Then the full significance of the clearing order becomes revealed very emphatically. The chaotic mass of twisted steel and splintered timber is thrown to one side or cleared right away with frenzied speed, and with very little consideration of salvage.

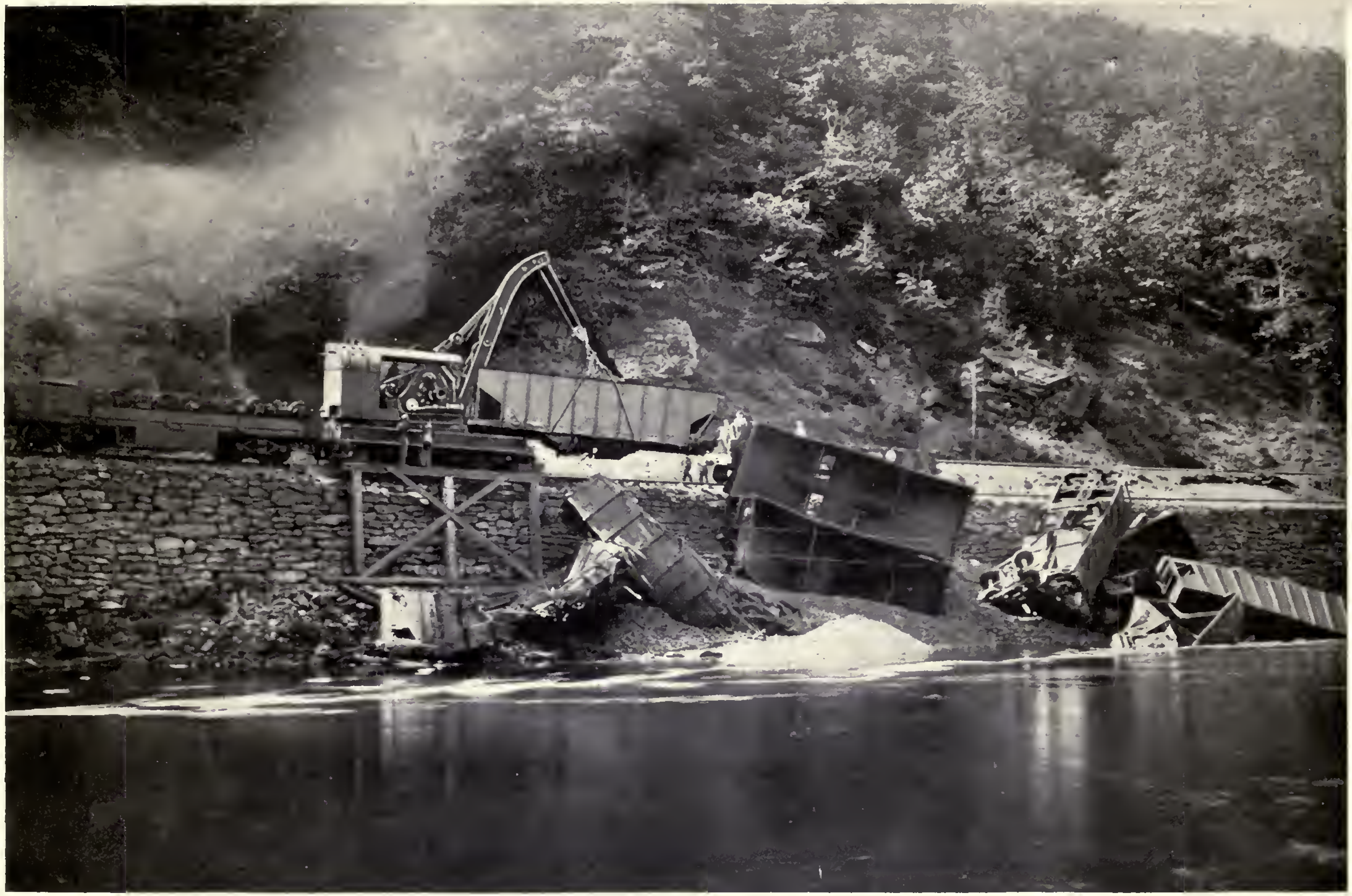
By permission of the Bucyrus Co.

THE POWER OF THE MODERN WRECKING CRANE.
Swinging a locomotive.

The "breakdown gang" is the emergency phase of railway life. The train engaged in this service is kept intact in its siding ready to answer a call at any hour of the day or night. Every tool—saws, hammers, hatchets, jacks, crow-bars and what-not—is kept in its allotted place. Likewise, the men forming the crew ever are on the alert, so that when the call comes for the "wrecking train," it is able to respond with the celerity of a fire-engine answering an alarm. Reaching the scene of the catastrophe, work is prosecuted with unflagging energy until the debris is cleared away, and the permanent way is repaired. At night the scene is particularly thrilling. The torn balks of wood are piled into huge heaps and fired, the crew toiling frantically in the fierce ruddy blaze of the pyres and the brilliancy of the flare lamps.

Nowadays the task of the wrecking crew is heroic indeed, owing to the increased weights and dimensions of locomotives and rolling-stock. When an engine may tip the scale at 80 or 100 tons; when a passenger-coach 60 feet in length, may weigh 40 tons; and when a high capacity wagon, $40\frac{1}{2}$ feet in length, representing 16 tons, filled with goods aggregating another 44 tons, are jumbled into a heterogeneous heap, truly herculean effort is required to straighten things out.

Therefore, in order to be able to comply with the clearing order, the implements used by the breakdown gang must be of unusual design and power. Indeed, the designing of such equipment has become a highly specialised branch of railway engineering. It was not so many years ago that a small crane of 15 tons capacity proved completely adequate for wrecking operations, but to-day such a tool would be worse than useless upon the great railways of the world. Accordingly, as the mechanical engineer



HOW THE TRACK IS CLEARED WITH FRENZIED HASTE.

An Industrial Works 70-ton crane clearing the debris of a derailed mineral train. The ponderous steel cars are lifted bodily.

has evolved larger and heavier engines, coaches and wagons, so has the crane-builder progressed in the augmentation of the capacity of his wrecking crane, until to-day a locomotive weighing 120 or more tons can be picked up and slung bodily through the air as easily as if it weighed only a matter of ounces. Recently, the top-notch in this peculiar field has been attained by an American firm. The Industrial Works, of Bay City, Michigan, has perfected a mammoth crane of 150 tons capacity, which is at present the most powerful in service.

Gigantic American Cranes.

This particular firm has made the wrecking crane one of its special studies, with the result that it is able to meet all requirements with the foregoing monster, or will supply a small implement able to lift only 5 tons or so. But it is the heavier type of crane which arouses the greatest interest, inasmuch as the design of such an implement within the limits of railway working bristles with many peculiar difficulties. In these Industrial Works' machines all technical questions have been answered in a highly successful manner. So far as the land of their origin is concerned, the demand for cranes of this character, owing to the dimensions and weights of the locomotives now in vogue, tends towards a crane varying in capacity from 60 to 120 tons, with perhaps an enhanced request for those ranging between 60 and 75 tons. Such lifting powers are sufficient to meet all ordinary demands, as cranes up to this rating are quite capable of coping with the average Pullman car, and the box type of wagon, representing 60 tons in loaded condition. Consequently it is the crane able to lift from 60 to 75 tons which is most generally seen. In view of the fact that, in the case of a big accident, the average wrecking train is likely to include at least two such cranes, it is quite feasible to handle a locomotive running up to 130 tons in weight.

These cranes are imposing, substantial creations with massive frames of iron and steel. The framework varies from 24 feet 1½ inches in length by 9 feet 6 inches in width, in the case of the 60-ton machine, to 26 feet 1½ inches long by the same width, in the case of the 120-ton crane. In every instance the body is carried upon two four-wheeled trucks, having steel wheels and correspondingly heavy hubs and journals. The boom in each instance is short and heavy, the overhang being reduced to the smallest possible limits, for convenience in travelling. Each truck is fitted with an air-brake, while one truck has a hand-brake attachment with removable staff. Seeing that the crane is restricted to the track, and is compelled to fulfil its work often at awkward angles, so as to get a perfect lifting and pulling grip upon the wreckage, it is made revolving, the whole slewing round upon a heavy turntable. In the case of the 60- and 75-ton cranes, the slewing in either direction is accomplished by means of a double friction clutch and gearing, so that it is unnecessary to reverse the engine for such work.

The Engines.

The engines are double; those for the 50- to 100-ton cranes have cylinders of 9 inches diameter by 12 inches stroke; while the 120-ton crane has cylinders with a diameter and stroke of 12 inches. In all cases the Stephenson link reversing motion is used to enable the engines to be operated in either direction when required. The boiler is of the submerged flue type, the dimensions varying according to the capacity of the crane. In the higher-powered machines—those ranging from 100 to 120 tons capacity—stability is assured by means of a complete system of telescopic outriggers on rollers, all of which are self-contained within the car body, the centre outrigger being provided with special ratchet mechanism for pulling it in either direction.

The very character of the work of the railway wrecking crew demands quick

operation, and in the designing of the above machines this salient factor has not been overlooked. In the majority of cases the implement is called upon to handle loads far below the rated capacity. Consequently, ease and dispatch in working are essential features. At the same time the crane must be able to lift its maximum load with equal ease and celerity when the occasion demands. These machines likewise meet this consideration very completely. They are able to hoist the heaviest rated load at the rate of 10 to 15 feet per minute, which, as experience has shown, is adequate for ordinary purposes. Slewing is equally rapid, the 120-ton crane being able to swing a light or maximum load a complete revolution in sixty seconds.

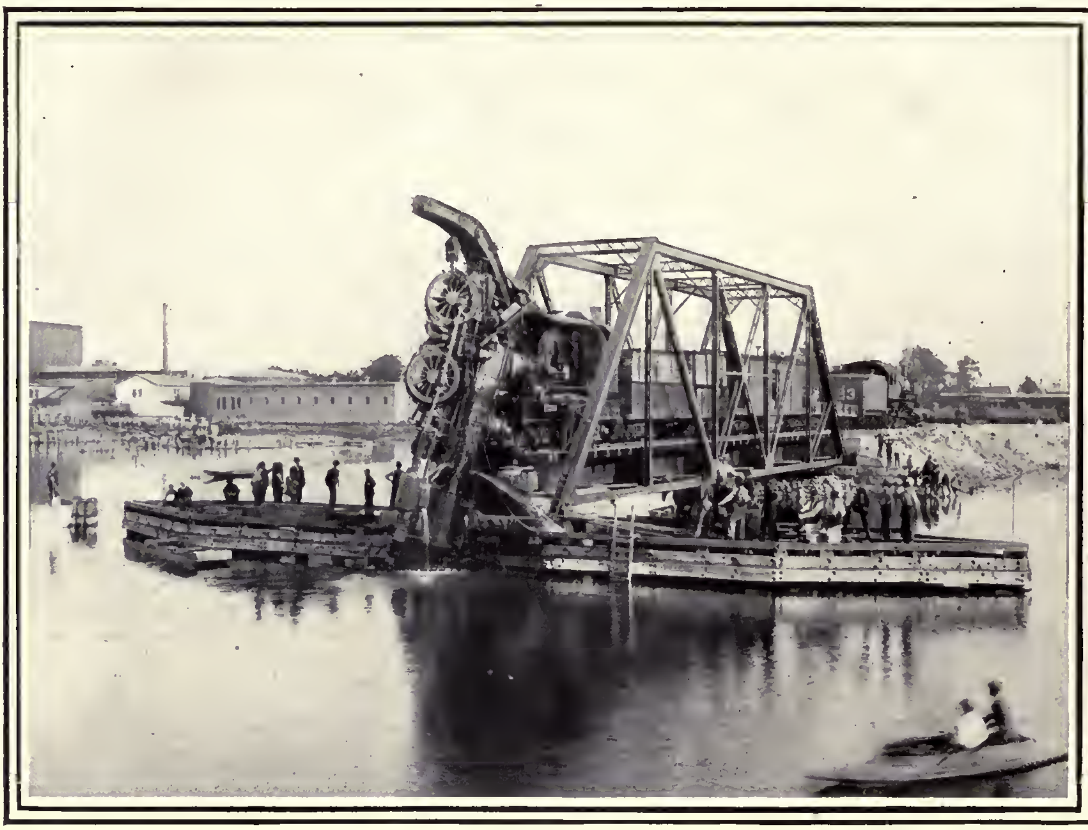
As may be supposed, these cranes are of immense weight. The 60-ton crane, for instance, including all equipment and in working order, weighs approximately 68½ tons, distributed over a wheel-base of 17 feet 6 inches, while the 120-ton crane weighs, under similar working conditions, 95 tons, which is distributed over a wheel-base of 19 feet 8 inches. In the latter machine there is sufficient rope on the main hoisting drum to operate the block a distance of 30 feet from the boom.

At times the wrecking crews upon the railways of North America are called upon to perform almost superhuman work. On one occasion I witnessed the removal of the wreck of a train which had jumped the rails through fouling an obstruction, and had plunged into a river 30 feet below. The result was a terrifying pile of huge box-wagons, packed upon the top of the submerged locomotive. Two 75-ton wrecking cranes, however, made short work of the scrap-heap. The majority of the wagons had broken up, and had to be retrieved in large pieces, which were deposited upon trucks for removal to the yards. Those wagons which were not seriously damaged were lifted bodily in the air, notwithstanding that they represented a dead load of 50 tons or more, and were re-deposited upon the metals to be hauled slowly to the

THE MOST POWERFUL WRECKING CRANE YET BUILT.
This appliance, designed by the Industrial Works, is able to lift 150 short tons at 17 feet radius.

nearest sidings. In order to regain the locomotive, which was about 10 or 15 feet under water, divers were required. With great difficulty they burrowed under the engine, which had buried itself deeply in the mud, and finally they got heavy chain slings beneath it. When the word to haul away was given, the cranes spluttered and creaked and tugged desperately at the chains. The engine was reluctant to leave its slimy couch, but at last, with a kind of kick, it came away, and was drawn up on the embankment just clear of the water. It was a heavy Consolidation, scaling some 70 tons, but when it was high and dry, and with the chains still taut, the wrecking crew scrambled over and under it, attaching a new sling.

The "haul-away" order once more was rapped out, the cranes tugged at the load, and in a few seconds the engine was swinging in the air, slung round, and was deposited without a jar upon the metals ready to be hauled back, battered and torn, to the repair shops.



THE TRIUMPH OF THE MODERN WRECKING CRANE.
A Locomotive which had tumbled through an open drawbridge being lifted out bodily.

On another occasion a passenger-train had come to grief by tumbling through a burnt-out trestle bridge into a mountain rift some 35 feet in depth. The coaches were packed in a ghastly heap, and the superstructure in the majority of cases had been torn from the trucks by the impact of the fall. The wrecking crane was drawn up to the brink of the gap, and the crew swarmed over the pile, attaching the chains to the larger pieces. Then the crane engine snorted and groaned, the hoisting chain was drawn as taut as a bow string, and with a rending and splitting the roof and one wall of a Pullman coach was pulled

away, swung round, and dumped upon the embankment for the time being. The locomotive was not to be seen, being covered by the wreckage of the coaches. When at last the crew were able to reach the engine it presented a sorry sight. It was battered out of recognition. The boiler had been crushed in and torn off the frame. But within a few hours its remains were cleared out of the rift, and were piled up on trucks ready for removal to the scrap heap.

But possibly the most impressive illustration which I have witnessed of the power of the modern wrecking crane was in the reclamation of a big Mikado scaling a round 100 tons. The engine had been derailed, and had tumbled over on its side, breaking its couplings and throwing its tender athwart the track. The breakdown crane was brought up, and under its own steam —the majority of these cranes are able to propel themselves at about 4 miles an hour, so as to move up to the most favourable points of attack—it crawled towards the tender, which had been wrenched free. In the course of a few minutes this part of the locomotive was whisked out of the way. Then slings were passed under the locomotive, and it was lifted into the air clear of the track. The crane backed out of the way with its load, to permit the traffic, which had been held up, to pass over the repaired permanent way. At night, in the glare of powerful flare lamps, the crew set themselves to the task of restoring the locomotive to its normal upright position on the rails—a job which was by no means easy. Then the breakdown train was re-made up, and started off, dragging the two parts of the locomotive behind it as far as the nearest divisional point, where it was repaired sufficiently to be run back to the shops for overhaul. The ease with which the huge, ungainly weight of

AN INDUSTRIAL WORKS' BREAKDOWN CRANE LIFTING A WAGON BODY AND ITS LOAD TO AFFORD ACCESS TO THE WHEEL TRUCK.

A NASTY SMASH: THE LOCOMOTIVE FELL THROUGH AN OPEN DRAWBRIDGE ON TO THE DECK OF A VESSEL WHICH HAPPENED TO BE PASSING AT THE MOMENT: THE LATTER WAS SUNK BY THE IMPACT.

100 tons odd was slung through the air, however, served to convey a very forceful idea of the enormous power possessed by the crane.

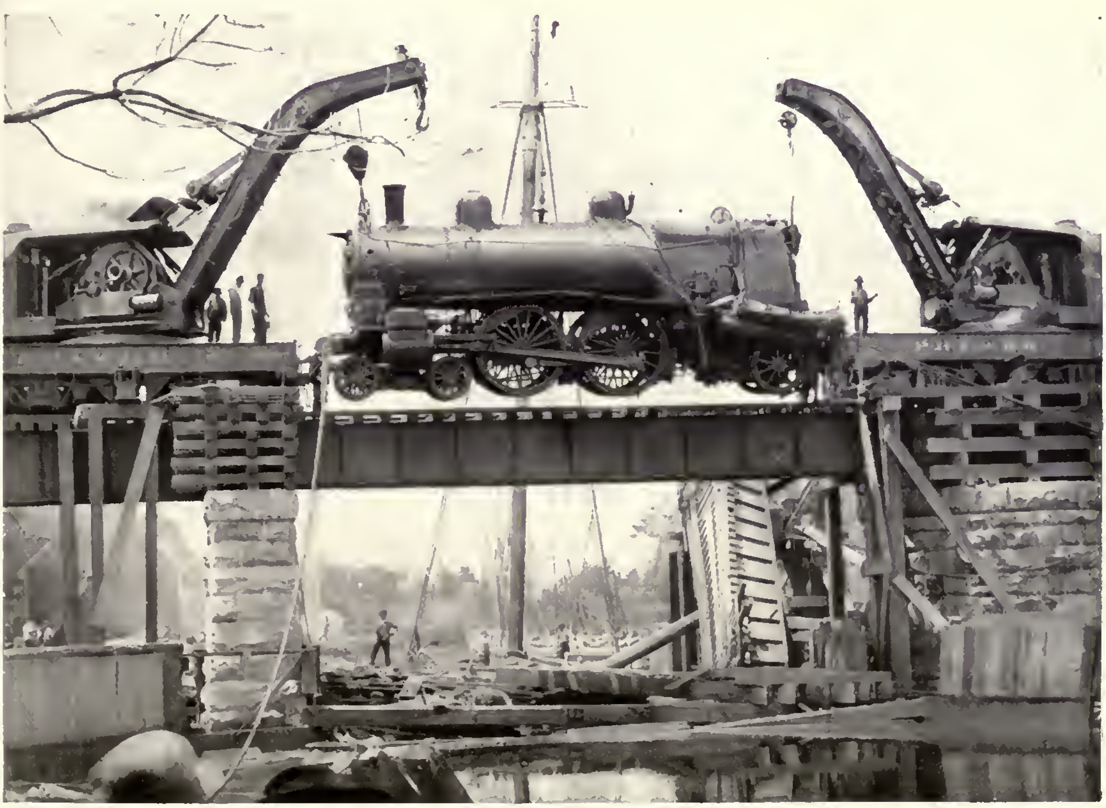
Although a crane of 150-ton lifting capacity is now in service, it is by no means indicative of the limit in this direction. Upon many foreign railways engines weighing from 200 to 400 tons are in operation. The crane-builder is compelled to keep pace with the advances of the locomotive engineer, but with engines of the foregoing weight the difficulties of design along the lines heretofore followed become increasingly complex. Indeed, it is maintained in some quarters that the 150-ton crane represents practically the extreme limits of such design. The enormous concentrated weight imposes a supreme tax upon bridges, trestles, and similar works, while, moreover, the limitations concerning height and width have to be borne in mind.

Under these circumstances it is believed generally that the mammoth crane of the future will follow quite different lines. In this connection the Stokes articulated crane offers a very complete solution of the problem. This machine has been invented by Mr. Wilfrid Stokes, the Managing Director of the Ipswich engineering firm of Ransomes and Rapier, Limited. The scope of this patent is the temporary increase of the wheel-base, together with the number of wheels upon which the weight of the crane is distributed. The crane carriage is mounted upon an eight-wheeled truck, with a four-wheeled bogie at each end, provided with a detachable articulated relieving girder, which can be attached or detached quickly from the headstock of the crane carriage by withdrawing a pin. Suitable

arrangements are incorporated with each bogie for transferring some of the load of the crane on to the former by means of this relieving girder. The bogie is free to swivel about the pin at the end of the relieving girder, while the relieving girder itself also is free to move laterally about its pin, connecting it to the headstock. Thus the fixed wheel-base of the crane is not increased by the addition of the bogies. The arrangement certainly is very flexible and suitable for running round sharp curves.

When the bogies are detached they can be lifted out of the way by the crane itself—slings are provided for this purpose—and can be deposited either on another track or elsewhere until required. The relieving girders are carried by the bogies in such a way as to be moved easily, either vertically or horizontally, so as to facilitate the insertion or withdrawal of the connecting pin. Thus coupling up or relieving only occupies from three to four minutes.

One of the first cranes built upon this principle was for the Great Indian Peninsula Railway, wherein the weight supported by each axle is 16¼ tons when the bogies are removed, and only 10¼ tons per axle when the bogies are attached for travelling. The wheel-base of the crane itself is 13 feet 3 inches, and 40 feet 3 inches with the two bogies. Prior to its dispatch to India this new type of crane was subjected to interesting and severe tests in England to demonstrate its advantages. Experience has confirmed very completely the contentions of the builders, and railway engineers have not failed to appreciate the fact that the articulated system offers a highly satisfactory means of securing heavy breakdown cranes for any class of work, without overstraining existing bridges and other

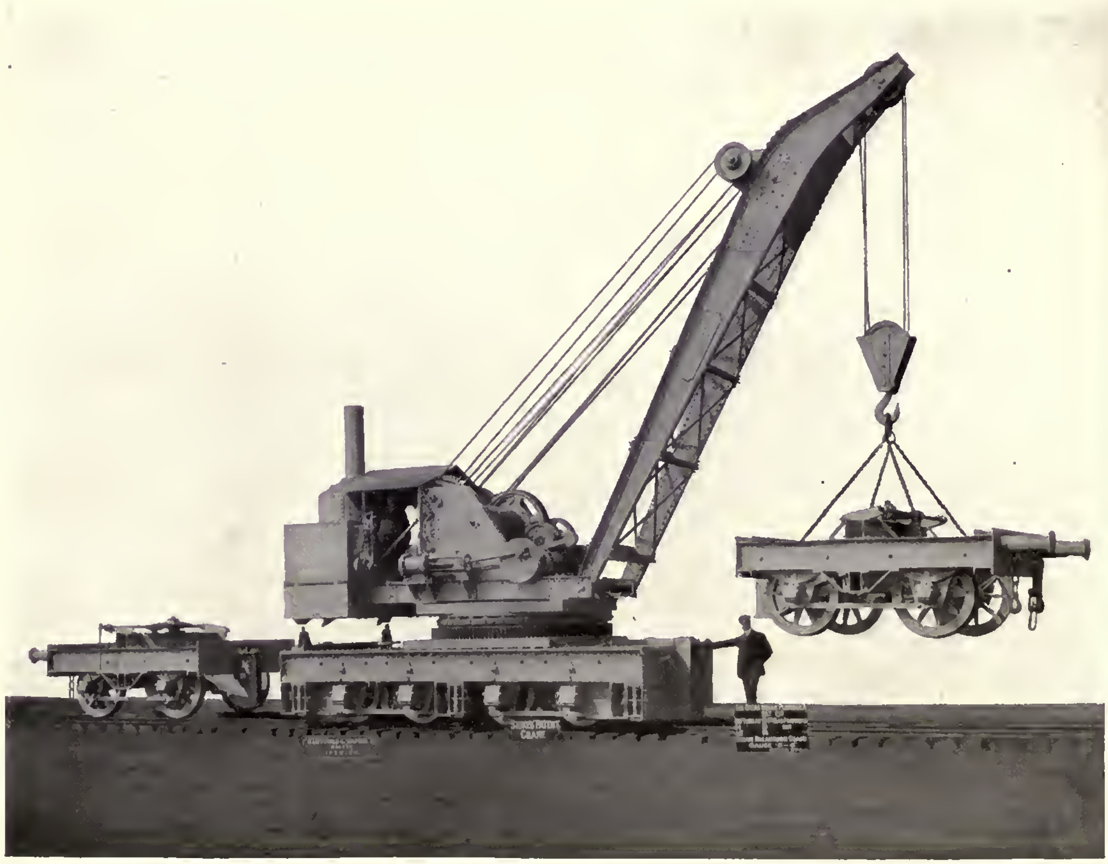


THE LOCOMOTIVE LIFTED FROM THE RIVER AND BEING REPLACED UPON A TEMPORARY TRACK BY THE WRECKING CRANES.

works over which they may have to pass during transit.

This articulated wrecking crane, of 5 feet 6 inch gauge, is able to lift 20 tons at a radius of 19 feet. In working order the weight of the crane alone is about 65 tons; complete with bogies approximately 78 tons.

Although designed essentially for wrecking purposes, the duties of these powerful machines are by no means confined to such operations. They constitute a handy tool to the railway engineer when bridges have to be rebuilt, while they are also exceedingly useful for handling heavy loads in the construction shops and yards. For instance, a defect in one of the wheels of a loaded high-capacity wagon may be discovered suddenly, rendering movement of the vehicle dangerous. Instead of removing the contents to another car, the breakdown crane is brought along, the vehicle and its load intact are lifted, and the repair is effected without disturbing the contents of the wagon. Again, when such a laden vehicle becomes derailed through fouling points, and the bogie trucks become damaged or thrown out of alignment, the wrecking crane enables the car to be replaced on the metals upon new trucks. Thus it will be seen that, taken on the whole, the "wrecking crane" is fully employed upon work widely divergent from that for which it was primarily designed.



THE STOKES ARTICULATED CRANE. BUILT BY MESSRS. RANSOMES AND RAPIER, LIMITED, AT THEIR IPSWICH WORKS FOR THE GREAT INDIAN PENINSULA RAILWAY.

Showing how the relieving bogies can be detached and slung clear of the road to allow the crane to be brought up closer to its work.

THE INTERIOR OF DOEPPERSBERG STATION AT ELBERFELD.
Showing method of suspending the car and the wire netting protection between platforms.

The Langen Suspension Railway

THE CURIOUS OVERHEAD LINE WHICH RUNS BETWEEN ELBERFELD AND BARMEN—A DISTANCE OF 8½ MILES

THE overhead railways common to New York and Chicago have been the butt of ridicule and joke since they first came into existence. But they have survived successfully the quips of the humorist, the fantastic delineations of the cartoonist, and the recriminations of the growler, inasmuch as they offer a successful solution of the intramural transportation question. The days when cinders and dirt descended upon horses, and when beads of oil fell down the necks of pedestrians below, have passed, because electric has supplanted steam working in accordance with the spirit of the age.

No one will deny that from the æsthetic point of view the overhead railway is an eyesore; it does not improve the beauty of an ugly street by any means. But that is not the issue. The public demands fast means of travelling from point to point in a busy centre, and in American cities preferred movement over an elevated track in broad daylight to transportation

through a tube in darkness. Moreover, at the time the overhead system was brought into being, subterranean railway building was in its infancy, and the public, in the wisdom of its generation, preferred the proved to the problematical.

That the American overhead system possesses many disadvantages no one will deny. Subsequent knowledge evolved superior systems of overhead transportation, but even these have not enjoyed an extensive vogue. The most important of these is the Langen system, which works upon the mono-rail principle, with the carriage suspended below, instead of running above, the track.

Some Ingenious Features.

The Langen system is a German invention, and is exemplified most potently in the stretch of line, nearly 8½ miles in length, connecting the two manufacturing towns of Elberfeld and Barmen. From the railway point of view it is a distinct novelty possessing many ingenious features. The permanent way comprises a system of latticed girders, one vertical and two longitudinal, which are assembled in such a way as to offer in section an I-form. The web of the I is constituted by the main girders, while the lateral girders form the upper and lower flanges of the I. The latter provide the requisite stiffness to the structure, while greater security is obtained by the introduction of diagonal bracing between the central and bottom lateral girders.

The track, properly so-called, consists of a single inverted T-rail along which run the wheels of the trucks, from which the carriages depend. This inverted T track is laid upon the I-beams forming the lower part of the structure, so as to offer clear movement for the wheels.

The permanent way is supported by massive frames springing from the ground, the shape of which varies according to the situation of the railway. Thus, where the line lies through the public streets an inverted U form of support is employed, so as to leave a clear headway for the full width of the thoroughfare. On the other hand, where the railway is built over the Wupper River, an A frame supersedes the inverted U used in the highways, the legs of the frame springing from either bank, so that the track is placed centrally above the waterway.

The span between each support varies according to the alignment of the line and the locality through which it passes, but the average is from 68¾ feet to 108¼ feet. The sharpest curves are about 300 feet radius. At intervals of 900 feet rigid double A-frames are introduced in order to give the requisite longitudinal solidity and stability to the road, the intermediate supports being provided with ball-and-socket joints, so that they may be free to move to meet the expansion and contraction in the track produced by climatic fluctuations. The road is built upon ample and substantial lines, the weight of the track, including supports, averaging about 2,000 pounds per lineal yard.

The Cars.

The cars are long, narrow vehicles, having tapered ends. They are 37½ feet in length by 6¾ feet wide and 8½ feet in height. Each vehicle has seating capacity for fifty passengers, and is provided with two doors opening inwardly in the sides, and doors at each end. In running order each car weighs 12 tons complete.

The carriage is suspended freely from two trucks spaced about 27 feet apart. Each truck is equipped with two wheels having double flanges, and mounted in tandem, thereby engaging with a single rail. Each truck is fitted with a 36-horse-power electric motor, and the current is drawn from the feed rail carried on the bottom of the lateral girder, through a slip shoe. The power is transmitted from the motor through gearing to the track wheels.

Every precaution is adopted to ensure

safety, and a derailment is impossible, even should a wheel or axle break, because the truck frames are carried round the track girder in the form of a hook. Play of only about a third of an inch is allowed, and in the event of a serious failure to the running wheels, the car is prevented from falling by the truck frames. Moreover, in running, oscillation of the car is limited severely, there being two projections on the lower part of the truck frames to prevent this movement. Consequently, travel, even at high speeds round the sharpest curves, is remarkably steady and free from swinging movement. In rounding the curves the cars assume a slightly inclined position, similar to that of the ordinary train under like conditions, but directly it enters a tangent, or section of straight track, the car reverts to the vertical position. The passengers, however, cannot perceive the slight inclination any more on this railway than upon the conventional line. Indeed, the inclination, even at the highest speeds upon the sharpest curves, is so very slight as to be practically imperceptible.

THE SUSPENDED RAILWAY OVER A PUBLIC HIGHWAY.
Showing the inverted U-shaped supports for the two tracks.

The stations are of special construction, being of the elevated type, with an arched roof. The platform is placed about 20 feet above the ground, so as to leave ample headroom for vehicular traffic in the street below. The platforms are approached by covered stairways similar to those adopted in the case of the American overhead railways, and the elevated sections of the London and provincial railways. Within the station, and extending throughout its entire length and width below the carriages, is stretched heavy wire netting

for the protection both of passengers and those in the thoroughfares beneath.

Seeing that the cars are suspended, it might be thought that a considerable rocking motion would be set up by passengers entering and leaving the vehicles, but this is overcome in an ingenious manner. Beneath the cars a series of springs are mounted, and these bear upon longitudinal wooden beams, extending through the station and beneath the sides of the cars. Consequently, when weights become imposed upon the platform side of the car, inclination or rocking of the vehicle is obviated by the springs pressing against this wooden beam.

At the Zoological Gardens terminus of the railway the cars are transferred from the one line to the other—there are two tracks—in a novel and simple manner. A switch is moved, and the car, by means of a sharply descending rail, glides on to a second track beneath the main line, swings round a loop, and is brought on to the second track over a sharply ascending rail and a lifting switch. Thus the delays at the terminus are reduced to a minimum, the system being safer, quicker, and easier than would be the case were backing out and shunting adopted.

Elaborate precautions are observed to ensure safety in travelling. A block system

THE RAILWAY ABOVE THE WUPPER RIVER IN ELBERFELD.
Showing the A-shaped supports.

working on the automatic track method is incorporated, wherein the signals are operated by the moving cars themselves. This arrangement enables the distance between two succeeding cars to be varied, according to the exigencies of the traffic, with very little difficulty. If desired, the distance between the vehicles can be reduced to two minutes, representing thirty trains per hour. The cars themselves are fitted with a Westinghouse air brake, a hand brake, and an electrical brake, so that ample facilities are carried for stopping the train. Should the emergency arise, these can be supplemented by reversing the motors.

The Maximum Speed.

Before this railway was built between Barmen and Elberfeld, an experimental line was laid down at Deutz, to demonstrate the features of the system, and its possibilities, as well as emphasising the safety of the principle. On this testing line the cars were driven at a speed as high as 47 miles per hour round the curves of 300 feet radius. When the Barmen-Elberfeld railway was completed, the authorities restricted the maximum speed to 25 miles per hour, including stops, but subsequently this limit was raised, so that now the average running speed is about 22 miles per hour, with a maximum of 31 miles per hour. In the tests, however, it was demonstrated that very high speeds were possible, and that curves of 1,200 feet radius could be negotiated safely at 94 miles an hour.

Eighteen stations are disposed along the railway, and the trip of 8½ miles between Barmen and Elberfeld occupies about twenty-five minutes. The railway was opened to traffic on March 1st, 1901. The cost of construction averaged about £53,000 per mile, including foundations, track, stations and rolling stock. From the public point of view this novel railway has proved highly popular, the traffic at times being very heavy, and its operation has been attended with a conspicuous immunity from accident, owing to the elaborate safety measures adopted. The electrical driving equipment is in duplicate, so that a complete breakdown and total suspension of the traffic is remote.

Yet, despite the success of the Langen Railway in this instance, it has not been adopted elsewhere. Shortly after its completion the underground tube railway came into vogue, and as any overhead system is certain to entail a certain disfigurement of the streets as well as being attended by numerous other inconveniences, this form of transportation has given way to subterranean methods. Even in Germany the system has not undergone further development, recent overhead lines being carried out in accordance with orthodox designs.

The Loschwitz Railway.

But there is one other interesting expression of the Langen suspension idea in the land of its genesis. This is the Loschwitz mountain railway. It is not an exact replica of the Barmen-Elberfeld line, because it is a combination of the Langen and counterbalanced rope systems. Still, it demonstrates the applicability of the idea to mountain railways, especially for short distances.

This line runs from Loschwitz, a small village on the banks of the Elbe, some 5 miles from Dresden, to the top of Rochwitz Heights, whence a magnificent panoramic view of the neighbouring city is obtainable. It is only 820 feet from end to end, while the maximum grade is 1 in 3.

The overhead track is carried upon thirty-three supports, ranging up to 49 feet in height, upon which is laid the track girder and rail for the wheels of the two overhead trucks from which the car is suspended. The two cars, each holding fifty passengers, and weighing 13 tons, differ from those employed on the other Langen Railway, being, in fact, more after the pattern of those generally used on mountain railways.

The driving system also is different. Each car is attached to the end of a travelling cable, $1\frac{3}{4}$ inches in diameter, which passes round a large drum at the upper station, driven by two 80 horse-power motors. Thus, as one car ascends the other descends. Elaborate safety devices and operating arrangements similar to those used upon aerial cableways are incorporated to secure the safety of travellers. The complete journey is accomplished in three minutes, and the railway is capable of handling 15,550 passengers each way per day.

This application of the Langen system, which was opened to the public in May, 1901, prompted Herr Feldmann to design the aerial cable way up the Wetterhorn, as described in a previous chapter. As a matter of fact, it was responsible for the development of this type of mountain railway which now is being taken up so extensively. It was by no means a difficult evolution, seeing that the main difference between the two ideas is the utilisation of a flexible cable for the track, instead of a rigid rail, as advocated by Langen, the inventor.

CAR ROUNDING A 900 FEET CURVE AT HIGH SPEED.

THREE LONDON AND SOUTH WESTERN EXPRESSES AT BATTLEDOWN JUNCTION.

From the painting by F. Stafford, presented to the L. & S.W. Railwaymen's Institute, Vauxhall, by the late Dugald Drummond, Esq., Mechanical Engineer to the L. & S.W.R.

11

Famous Expresses—I

SOME ENGLISH AND AMERICAN "FLYERS" COMPARED

PROBABLY in no other part of the world is the speeding-up in railway travelling so emphasised at present as in Great Britain. Certainly no other country can parade such a long list of flyers running in regular daily service, or show such fast schedule times in proportion to mileage as the British lines. Here and there one particular foreign train compels attention in point of pace, but such are exceptions, not the rule, as in British practice. Consequently, taken on the whole, this country stands supreme in point of speed.

In a previous chapter I have drawn attention to the remarkable running of the Atlantic City flyer, which is timed to reel off the 55½ miles between Philadelphia (Camden) and Atlantic City in 50 minutes. It is the fastest train for this distance in the world, but its performance in travelling speed is equalled, if not exceeded, by a British train. This is the Newcastle to Sheffield express of the North Eastern Railway, over the stretch of 44·125 miles between Darlington and York, which it is timed to cover in 43 minutes. At first glance there seems to be no comparison between the two achievements, seeing that the average start-to-stop speed of the American train is 66·6 miles per hour to cover the distance in the time allowed, as compared with an hourly average of 61·57 miles in the case of the North Eastern express, but a little closer investigation reveals the striking character of the latter's performance.

In order to secure a fair comparison, it is necessary to take into consideration the nature of the road traversed, the relative size and power of the locomotives employed, the fluctuations in load, and the adverse factor of junctions. The American train is hauled by a very powerful engine of the Atlantic type, the load does not vary very considerably, and the line runs through virtually open country from end to end. On the other hand, the English train is hauled by a relatively light, small machine, the load varies very considerably, and, owing to the North Eastern Railway serving a densely populated territory, liberally provided with railway facilities, numerous junctions serve to hinder the opportunities of making pace. From the grade point of view the English railway has the advantage, since there is

OILING UP THE NORTH EASTERN RAILWAY'S FAMOUS "FLYER."

THE "FASTEST TRAIN IN

The North Eastern Newcastle to Sheffield Express, which is timed to cover the 44¼

Photograph by kind permission of R. J. Purves, Esq.

THE BRITISH EMPIRE."
miles between Darlington and York in 43 minutes, snapped at 70 miles per hour

only one bank, rising at 1 in 366 for 2½ miles out of the 44, the balance being virtually level.

The average load of the North Eastern train is six coaches, representing about 150 tons, though in the summer the train often is called upon to draw nine and ten vehicles, bringing the load up to some 250 tons. It is always hauled by one of the fine North Eastern 4-4-0 express locomotives, weighing with tender, in working order, only 89·6 tons—a comparatively small machine for these days and for such work. The train leaves Newcastle at 12.20 p.m., is timed out of Darlington at 1.9 p.m., and is due to arrive at York at 1.52 p.m. As a matter of fact, it generally arrives at York from two to three minutes ahead of time. There is no doubt but that this train easily could achieve the distinction of being the fastest train in the world only, unfortunately, it is liable to be checked by signals in approaching York, especially when running before time. Were a clear road possible, such as is the case between Philadelphia and Atlantic City, the 44 miles could be reeled off in 37 minutes, or even less. Indeed, one of the drivers claims to have made the run in 37 minutes, but, unfortunately, no one was timing him on the occasion, so that the run has not received official recognition.

LOGS OF THE 12.20 P.M. NEWCASTLE TO SHEFFIELD EXPRESS — AS BETWEEN DARLINGTON AND YORK

	Schedule time	No. of Run . . . / Engine.—Class R, No. . / Load.—Weight empty (tons) / Weather Conditions . .	1 / 1147 / 152 / *Strong side wind*	2 / 2012 / 152 / *Calm*	3 / 1209 / 152 / *Calm*	4 / 1672 / 152 / *Calm*	*Average pnt. to pnt. speed on run No. 4. Engine* 1672
Mls. Chns.	*p.m.*		*Mts. Secs.*	*Mts. Secs.*	*Mts. Secs.*	*Mts. Secs.*	
—	1.9	Darlington . . *Start*	—	—	—	—	—
—		,, *Platform end pass*	0 46	0 46	0 49	0 46	—
2 48		Croft Spa . . ,,	4 16	4 20	4 10	3 54	40·0
5 18		Eryholme . . ,,	6 47	6 58	6 48	6 14	67·5
6 74		Cowton . . . ,,	8 20	8 35	8 26	7 40	71·1
10 32		Danby Wiske . . ,,	11 24	11 34	11 26	10 33	72·3
14 14	1.23	Northallerton . . ,,	14 46	14 50	14 43	13 46	70·4
17 46		Otterington . . ,,	17 47	17 43	17 34	16 36	72·0
21 74	1.30½	Thirsk . . . . ,,	21 21	21 8	21 3	20 4	75·2
26 10		Sessay . . . ,,	24 52	24 30	24 27	23 33	72·3
28 4		Pilmoor . . . ,,	26 30	26 2	26 0	25 9	72·2
30 60		Raskelf . . . ,,	28 45	28 11	28 9	27 23	72·5
32 75	1.41	Alne . . . . ,,	30 30	29 52	29 53	29 9	74·3
34 31		Tollerton . . ,,	31 45	30 59	31 3	30 20	73·5
38 50		Beningbrough . . ,,	35 15	34 18	34 26	33 45	74·4
42 43	1.49	Poppleton Junction . ,,	38 40	37 26	*38 43	37 0	72·2
—		York *Platform end, pass*	40 44	*40 18	41 8	38 46	—
44 10	1.52	,, ... *arr.*	41 40	41 5	41 48	39 34	37·1
	43 Mts.	Net time, minutes . .	41⅔	40	40¼	39½	
		Maximum speed . .	75·0	78·9	78·9	78·2	

* Dead slowed by adverse signals.

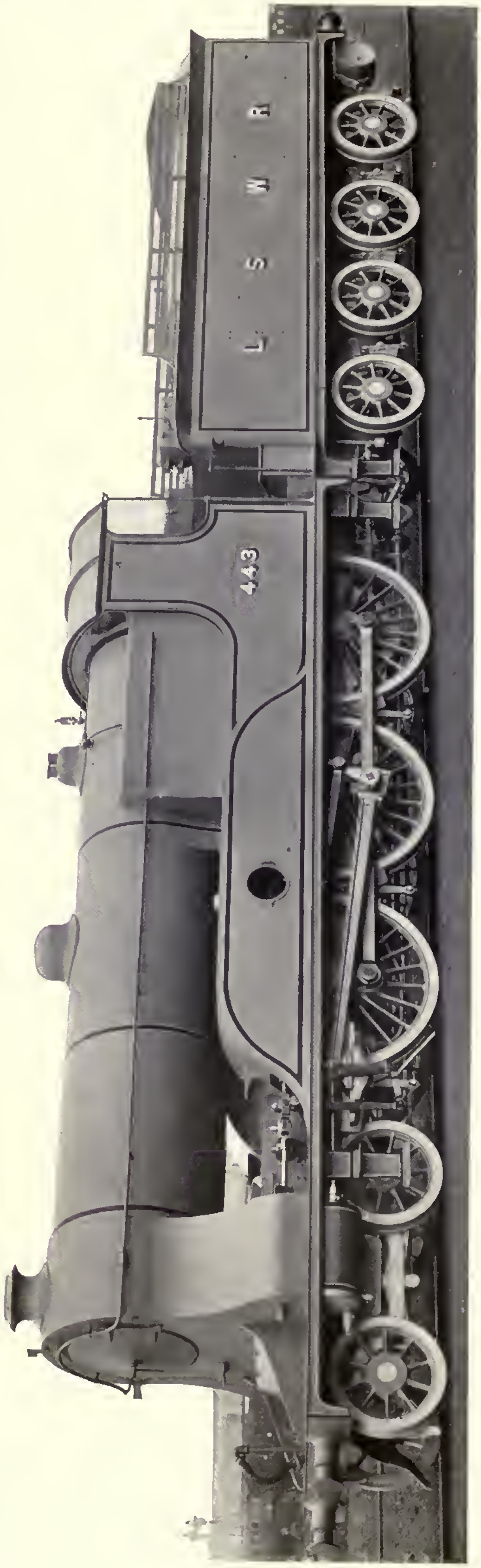
For the purpose of showing what running performances this train can achieve, I have been favoured, through the courtesy of Mr. R. J. Purves, of the Signalling Engineering Department, with the accompanying logs, which were run under his own timing. Each of the four runs was made on a Saturday, when the train usually is heavily crowded; in fact, in Run 4 the passengers were standing in the corridors.

These logs shows the point-to-point speeds. In connection with the first three runs a striking similarity in the acceleration of the respective engines is shown. In each

case the speed on passing Croft Spa was exactly 60 miles per hour. On Run 2, with engine No. 2012, the average speed over the 34 miles between mileposts 37 and 3 works out at 73·6 miles per hour.

Run 4, with engine 1672, shows a most phenomenal start, and it is doubtful whether a parallel thereto could be found anywhere. From Darlington to Croft the road is level, but this engine got into its stride so quickly that the impression of descending a steep gradient was conveyed, because a velocity of 60 miles an hour was attained within three minutes of starting from rest. Even after passing Croft, and when climbing the bank of $2\frac{1}{2}$ miles length at 1 in 366, the train continued accelerating until, when passing through Eryholme, 69·2 miles an hour was notched. Clearing the bank, 70 miles an hour was exceeded immediately, and maintained over the succeeding 35 miles of virtually level road until steam was shut off at the second milepost out of York, the 35 miles being covered in 28 minutes 50 seconds, giving an average of 78·2 miles per hour. The maximum speed attained was 78·2, a velocity which even the crack American train would find it difficult to equal.

I have also been able to obtain another log with reference to Class R locomotive No. 1207, shortly after it was fitted with a superheater. This engine, at the time of writing, was selected by the company to work the "flyer" regularly, the driving crew being changed weekly. On the day of this run the engine was hampered badly by a strong south-west wind, while the load was slightly heavier as compared with the preceding runs. Still, to put up a net running time of 40·75 minutes for the 44·125 miles, under the circumstances, constitutes a remarkably fine piece of work. In this case a speed of 60·8 miles was registered in passing Croft Spa, while 60 miles an hour was maintained at the top of the bank at Eryholme. This run



Photograph by permission of London and South Western Railway.

THE POWERFUL 4-6-0 "DRUMMOND" LOCOMOTIVE WHICH HAULS THE NON-STOP TWO-HOUR EXPRESSES BETWEEN LONDON AND BOURNEMOUTH. 108 MILES—AVERAGE SPEED 54 MILES PER HOUR

comes out with a maximum speed of 75 miles an hour during the journey, and there is no doubt that had the conditions been as favourable on this trip as on the occasion when locomotive 1672

Photograph by permission of London and South Western Railw

THE LONDON-BOURNEMOUTH TWO-HOUR EXPRESS RUNNING THROUGH EASTLEIGH.

acquitted herself so finely, the latter's record would have been lowered.

LOG OF THE 12.20 P.M. NEWCASTLE TO SHEFFIELD EXPRESS AS BETWEEN DARLINGTON AND YORK.

Mls.	*Chns.*	ENGINE.—No. 1207, Class R (superheated). LOAD.—165 tons, empty. WEATHER.—Strong S.W. wind.	*Mns.*	*Secs.*
—		Darlington . . *Start*	—	
—		,, *Platform end, pass*	0	46
2	48	Croft Spa . . ,,	4	1
5	18	Eryholme . . ,,	6	35
6	74	Cowton . . . ,,	8	9
10	32	Danby Wiske . ,,	11	11
14	14	Northallerton. . ,,	14	34
17	46	Otterington . . ,,	17	34
21	74	Thirsk . . . ,,	21	13
26	10	Sessay . . . ,,	24	48
28	4	Pilmoor. . . ,,	26	24
30	60	Raskelf . . . ,,	28	39
32	75	Alne . . . ,,	30	24
34	31	Tollerton . . ,,	31	38
38	50	Beningbrough . ,,	35	6
42	43	Poppleton Junction ,,	38	23
—		York *Platform end, pass*	*40	24
44	10	,, ... *arr.*	41	3

Net time, 40¾ minutes. Maximum speed, 75·0 miles her hour. * Signal check.

Inasmuch as the comparing of achiev ments always appeals to those interested railway running performances, the faste runs of the American rival between Phi delphia (Camden) and Atlantic City,- distance of 55½ miles, are given on t next page.

Thus it will be realised that, all thin considered, the achievements of the Nor Eastern crack train compare exceeding favourably with its American rival, a certainly entitle it to the distinction being the "fastest train in the Briti Empire."

Turning from the north to the south England, although the circumstances a somewhat different, some first-class ru ning performances are to be record upon the London and South Western Ra way. The services of this system natu ally fall under three groupings—first, t long-distance trains between London a North Cornwall via Salisbury; second and thirdly, between London, Southam ton, and Weymouth; and London a Portsmouth respectively. The first-nam route is far from being conducive to hi speeds, owing to the undulating charact

Date	*From*	*To*	*Time*	*Average Speed Miles per Hour*
July 14, 1897	Camden	Atlantic City	46 min. 30 secs.	71·6
July 4, 1900	Camden	Atlantic City	44 ,, 15 ,,	75·2
July 20, 1904	Camden	Atlantic City	43 ,,	77·4
May 14, 1905	Atlantic City	Camden	42 ,, 33 ,,	78·26
June 19, 1906	Camden	Atlantic City	43 ,, 30 ,,	76·7

of the country traversed, there being several long, severe rises, the heaviest of which is the Honiton bank, with a grade of 1 in 80 for 5 miles. So far as the Southampton and Portsmouth roads are concerned, easier grades are encountered, there being a long, steady upward pull from London (Waterloo) to Basingstoke, followed by an equally steady descent to Eastleigh.

The feature of the Southampton route is the two-hour non-stop service between London and Bournemouth, a distance of 108 miles, which represents an average speed of 54 miles per hour. Seeing that this train during the summer months is patronised heavily, necessitating often ten coaches of 54 to 56 feet in length and weighing from 26 to 28 tons each, the load ranges between 260 and 280 tons empty, so that to complete the journey in 120 minutes dead indicates a smart task upon the part of the locomotive.

THE "SANTA FÉ DE LUXE" MAKING 65 MILES PER HOUR.
This weekly train covers the 2,263 miles between Chicago and Los Angeles in 63 hours, giving an average speed for the whole journey of 36 miles per hour.

In the early years of the first decade of the present century the London and South Western held paramount position in the travelling time between London and Exeter, a distance of 171¾ miles. It was the first company to bring the two points within 210 minutes' travelling of one another, its competitor requiring an additional five minutes to connect the two points, though the latter route was 22 miles longer. The rival endeavoured to reduce the time

handicap, but the competition resulted in the South Western Company clipping fifteen minutes off the timing, making the 171¾ miles in 195 minutes. The run was divided into two non-stop sections—London to Salisbury, 83¾ miles, where engines were changed, and thence to Exeter, 88 miles. Further paring of the timing ensued until, competition between the two companies being brought to an end, a schedule of 192 minutes became standardised. As, however, this includes a five minutes' stop at Salisbury to change engines, the net running time is 187 minutes, giving an average of 55·1 miles per hour, with an average load of 280 tons empty.

The "Drummond" Locomotive.

When the London and South Western first made a bid for speed, the fastest trains were usually double-headers, but the false economies arising from this system of working became recognised as the traffic grew. Consequently, larger and more powerful locomotives, capable of working the trains unaided even over the heaviest banks, were evolved by the late Mr. Dugald Drummond, the mechanical engineer-in-chief to the system. The latest engines of his design are the finest on the system, and work all the heavy express traffic. They are of the 4-6-0 class, with four cylinders and working simple. The cylinders have a diameter of 15 inches and a stroke of 26 inches. The bogie wheels are 43 inches in diameter and the three pairs of drivers 79 inches in diameter. The heating surface of the flue and water tubes is 1,780 square feet, and of the fire-box 140 square feet, giving a total heating surface of 1,920 square feet. The fire-box has an area of 31·5 square feet, and the boiler pressure of the steam is 200 pounds per square inch. The engine weighs 68 tons, and with the tender, having capacity for 4,500 gallons of water and 4 tons of coal, represents complete, in working order, 108 tons, while the over-all length is 63 feet. The latest Drummond locomotives used in the express traffic may not compl with æsthetic considerations, but there no denying their hauling power and spee

The "Santa F de luxe."

One of the finest trains in America the "Santa Fé de luxe" of the Atch son, Topeka, and Santa Fé Railway. The problems facing express working upon this railway are of a peculiarly difficu character, and in the run from Chicag to Los Angeles the train has to ove come no fewer than six mountain rang where the grades are staggering. Aft leaving Chicago the line has a pra tically level run of 240 miles to Fo Madison, the maximum grade westwa being 31·68 feet per mile. The 200 mil from Fort Madison to Kansas City ha a similar maximum grade, except at o point, where there is a rise of 42·24 fe per mile. Kansas City is at an elev tion of 750 feet above the sea, but withi the next 640 miles the train has to clim to 7,608 feet, the summit of the first rang at Raton. For the last sixteen miles to th summit the train has to struggle again a rise varying from 106 to 185 feet p mile, followed by an immediate desce of 175 feet per mile. Passing Raton, th line drops 1,858 feet, climbs 980 feet, fal again 500 feet, once more struggles to 7,42 feet, descends 500 feet, followed by anoth ascent of 1,011 feet from an altitude of 6,23 to 7,241 feet at Glorieta, the second summi these violent fluctuations in level occurri within 200 miles. Then comes anoth heavy drop of 2,307 feet to Albuquerque i the course of 60 miles, followed immediatel by another heavy pull up 2,309 feet in 16 miles to the summit of the Continent Divide. There is a further heavy fall t Winslow at 4,848 feet in the next 160 mile followed immediately by a stiff ascent to th Arizona Divide at 7,300 feet in the cours of 80 miles. Thus four summits have bee overcome within a distance of 600 mile

The railway falls away from an altitud of 7,300 feet at the Arizona Divide to 57

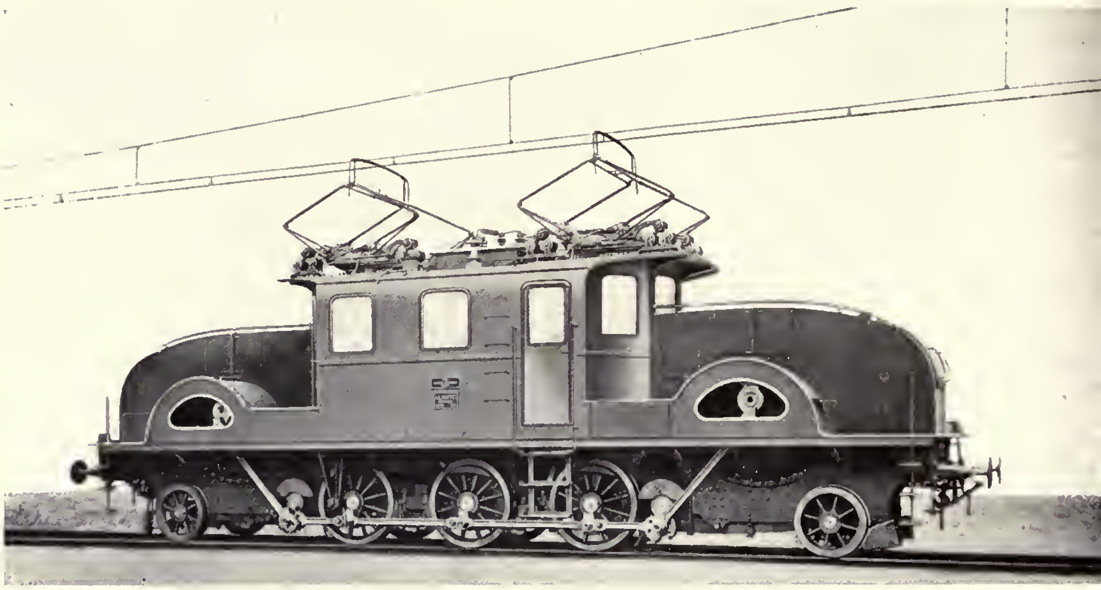
feet at Needles, the 6,665 feet difference in level being overcome in 600 miles. After leaving Needles the line rises 1,930 feet in 40 miles, and drops 1,897 feet in 60 miles to Amboy. Then comes the terrible upward pull to Cajon summit at 3,820 feet altitude, involving a climb of 3,209 feet in about 90 miles. Now ensues a terrific sudden drop of 2,744 feet to San Benardino, followed instantly by a rise of 2,949 feet to Tehatchapi summit, which is about 50 miles by rail from Cajon summit. For 25 miles the rise through the Cajon Pass varies between 116 and 158·4 feet per mile, while there are 25 miles of grade at 116 feet per mile to the Tehatchapi summit.

When the Santa Fé set out to accelerate the train service over the 2,263 miles between Chicago and Los Angeles, it was faced with a very stiff proposition. Yet there was public demand for a crack train between these two cities, and the public was quite prepared to pay for the accommodation. The railway built a special train, one of the most luxurious in the country, and in 1911 inaugurated the Los Angeles Limited, undertaking to complete the journey in 63 hours. This represents an average speed of 36 miles per hour from terminus to terminus. But, seeing that speed over the heavy mountain banks, even when additional motive power is taken on, must fall, it will be seen that upon the more favourable parts of the track velocities of 65 and 70 miles an hour must be attained.

But an average of 36 miles was a decided improvement upon competitive trains between the two points, inasmuch as the "Santa Fé de luxe" completes the journey in five hours less than its nearest rival on the westward run, while coming east the same train shows an advantage of no less than eight hours. For the improved facilities travellers by this train are mulcted an extra £5 over and above the ordinary fare. But they do not grumble. The public has patronised the train so enthusiastically that it is a complete success.

THE ATCHISON, TOPEKA, AND SANTA FÉ "CALIFORNIA LIMITED" MAKING SPEED OVER THE HEAVY GRADE OF 158·4 FEET PER MILE THROUGH THE CAJON PASS.

To maintain the schedule a powerful "Mountain Mikado" helper locomotive is attached as pilot.



By permission of Messrs. Siemens, Ltd.

THE 2-6-2 ELECTRIC LOCOMOTIVE USED ON THE PRUSSIAN STATE RAILWAYS.

Some Electric Giants of Europe

THE DEVELOPMENT OF ELECTRICAL POWER HAS LED TO THE PRODUCTION OF SOME WONDERFUL ELECTRICALLY DRIVEN LOCOMOTIVES, WHICH ARE HERE DESCRIBED

ALTHOUGH electric traction has not made very great strides in Great Britain in connection with main-line working, it has made remarkable headway upon the continent of Europe. This is particularly the case in those countries where economic conditions virtually have compelled such a movement. Italy, Scandinavia, and Switzerland are almost exclusively dependent upon foreign sources for all fuels; on the other hand, each has an abundance of water-power running to waste. It is not surprising, therefore, in the light of modern knowledge, that these countries should be devoting their energies to harnessing these sources of energy for the movement of traffic over their respective railway systems.

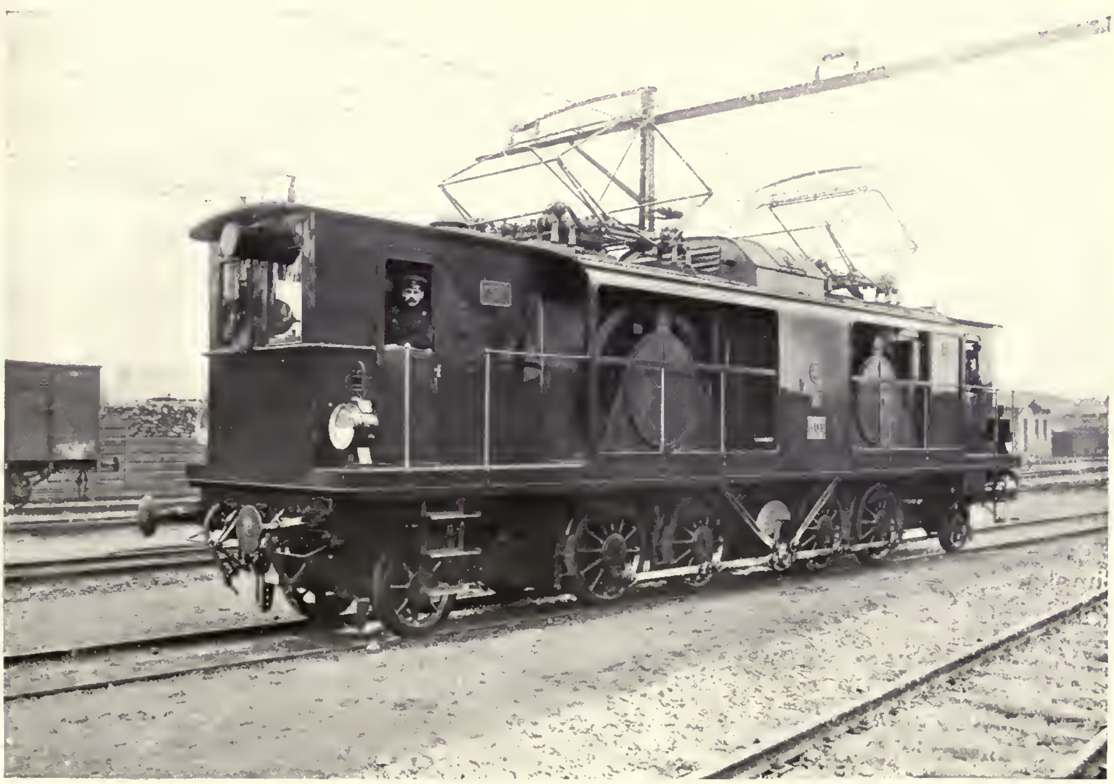
So far as Switzerland is concerned, an the same applies to Italy in a lesser de gree, electric traction practically became necessity to work traffic through the lon Alpine tunnels. Steam operation is bese with many difficulties, not the least which is the fouling of the tunnels b steam and smoke, while the problem attending ventilation in order to rend the temperature within the tunnels toler able to the travelling public became acut True the St. Gotthard tunnel, which is th longest in the country, has been worke by steam ever since its opening, but onl because there was no alternative. But th traffic of the Swiss railways has advance by leaps and bounds until at last th St. Gotthard became taxed to its utmos capacity. The smoke trouble governed th

situation; the tunnel became the limit of the line.

Consequently when the Simplon was taken in hand electrical manufacturers upon the Continent contemplated the feasibility of working it by electric traction. The Government had left the question open until the work was completed, or until electric traction had reached a more advanced stage, so that they might be in a position to view and discuss the problem more comprehensively and lucidly. But the manufacturers did not wait for completion; they formulated proposals for achieving the desired end in anticipation.

Among these firms was that of Messrs. Brown, Boveri, and Company, of Baden, Switzerland, a concern which, founded by an Englishman, has grown and spread its tentacles all over the world. In the autumn of 1906 this firm approached the Swiss Federal Railways with an offer to instal a system of electric traction throughout the Simplon tunnel and railway, and to have it ready by the day the tunnel was opened to traffic. It was a big proposal, and in the light of contemporary knowledge was somewhat bold. Still, it was favourable from the Government's point of view, inasmuch as the company undertook to complete the work at its own expense, and if it should prove a failure, would remove it. The Government therefore stood to lose nothing, since, even if things came to the worst, they could introduce steam working immediately, so that there need be no interruption of traffic.

At first sight such a bargain appeared to be one-sided; the company seemed to be facing a heavy risk. But against this contention had to be placed the circumstance that Brown, Boveri, and Company already had completed several notable electric railway undertakings, such as the Görnergrat rack, the Jungfrau, and the Burgdorf-Thun railways. Although none of these



By permission of Messrs. Siemens, Ltd.

THE 1,250 HORSE-POWER 2-8-2 LOCOMOTIVE USED ON THE DESSAU-BITTERFELD RAILWAY.

installations approached that contemplated for the Simplon in magnitude, still, they provided the contractors with valuable experience and a basis for completing the larger and more important work.

The Government discussed the offer, but although it appreciated the fact that a unique opportunity would be provided for the purposes of comparing steam and electric traction upon a large scale, it did not accept it finally until the end of the year 1905. This delayed acceptance was disadvantageous to the contractors, as the tunnel was approaching completion, and they would have to hasten to have their work completed on time. On the other hand it was a fortunate circumstance, inasmuch as no time could be afforded to discuss the merits of the relative systems. The company had more familiar experience with the three-phase system up to that date than with any other, so decided immediately to instal it on the Simplon Railway.

The Offer Accepted.

The greatest anxiety arose in connection with the locomotives, but even this difficulty was overcome successfully. At the time the contractors had two three-phase 1,000 horse-power locomotives under construction for the Adriatic electric railways. So, in order to gain time, the Italian railway company was approached to ascertain whether it would waive its rights to these engines and allow them to be used on the Simplon line, the peculiar circumstances being explained. The Italian railway company readily consented to the proposal. The work of electrifying the tunnel was taken in hand without delay, and was pushed forward so satisfactorily that the installation was completed on time. In one respect the contractors had to make existing facilities serve their purpose. This was in regard to the power stations. The two water-power stations, at Brigue and Iselle respectively, which had been laid down to supply the machines used in

The Locomotive.

boring the tunnel were utilised for t purpose, merely being modified to m the new conditions. They were pur makeshifts and served their purpo very effectively, although their operati was far from being as reliable as v desired. Still, their temporary charac was recognised, and it was appreciated tl the defects which arose from time to ti in connection therewith would be entir overcome when a specially designed pow house was erected. These two static supplied current at 3,300 volts, and periodicity of 16 cycles per second, a fortunately the two locomotives und construction for the Italian railways h been designed for this pressure and f quency.

The locomotives, which were giants their day, were of the bogie type, with f axles, three of which were driven, so that the machine coincided with the 2–6–2 Whyte numerical classification. The traction motors w placed between the three pairs of drivi wheels, and both drove on the mid axle by means of a bar coupling th rigidly together. This axle in turn dro the other two by means of a coupli rod, so that gears were eliminated. T over-all length of the locomotive was feet 6 inches with a distance of 23 f between the bogies, and 16 feet 1 ir between the driving axles. The drivi wheels were 5 feet $4\frac{1}{2}$ inches diameter, a the bogie wheels 2 feet $9\frac{1}{2}$ inches in diamet The total weight of the machine was tons. Of this total 34 tons represent the mechanical section of the equipme and 28 tons the electrical portion, wh 42 tons were imposed on the driving whee The weight of each motor complete w $10\frac{3}{4}$ tons, and they were the lightest their output which had been built up that time. The normal rating of the t motors working together was 900 hor power, with a maximum of 2,300 hor power, the normal speeds being 21 mi

Elect Gian

By permission of Messrs. Siemens, Ltd.

THE 1,800 HORSE-POWER 2-6-2 SIEMENS ELECTRIC LOCOMOTIVE HAULING A 7-CAR TRAIN ON THE DESSAU-BITTERFELD RAILWAY.

and 42 miles per hour. The draw-bar pull at 42 miles per hour ranged from 7,700 pounds normal to 20,000 pounds maximum, and from 13,500 pounds normal to 31,000 pounds maximum at 21 miles per hour.

Supremacy of Electricity.

In deciding the installation it was stipulated that the speed of acceleration, when starting on the higher speed with a train weighing 300 tons, should be 0·5 feet per second, per second, for which a draw-bar pull of 16,000 pounds had to be exerted, while, when starting with a goods train weighing 400 tons at the lower speed, the rate of acceleration was to be 0·36 feet per second, per second, a draw-bar pull of 20,000 pounds being necessary in this instance.

For a time steam trains were run side by side with the electric trains in order to obtain conclusive comparative data, but it was not long before the electric traction asserted its undoubted supremacy in such a manner as to induce the abandonment of steam traction. Ultimately the installation was accepted and taken over by the Government. At the same time the possibilities of electric traction for main line working became emphasised so strongly that the Swiss Government forthwith turned its attention to the question of electrifying the whole of the lines embraced in the Federal system, which work is being accomplished slowly but surely.

Swedish Developments.

Since the electrification of the Simplon Railway many powerful electric locomotives have been designed, and many important main-line electrification schemes have been taken in hand. This is particularly the case in Sweden, where elaborate experiments were continued over a period of many years in order to thresh out the issue in all its bearings. It has now been decided to electrify the main line of the State system between Kiruna and Riksgransen. An enormous mineral traffic flows over this highway to Ofoten, the great ore-shipping point on the Norwegian coast in the Arctic circle, since this line traverses the heart of the Swedish ore mining territory, connecting it both with the Baltic at Stockholm and the Atlantic seaboard.

Fifteen powerful locomotives have been built by Messrs. Siemens, Limited, for the electrified section of this railway, which is 93·75 miles in length. The locomotives are of two types, one having a four-wheeled bogie at each end and two driving axles —4–4–4 type—and the other comprising an articulated system with two sets each having three pairs of coupled axles—0–6–6–0 type. The horse-power in each instance, however, is identical, 1,250, while current is supplied to the contact line at a pressure of 15,000 volts with a frequency of 15 cycles per second. This company also has built some powerful machines for the 22 miles of the electrified Dessau-Bitterfeld section of the Prussian State system. The most powerful are the 2–6–2 of 1,800 horse-power, the 4–4–2 type of 1,100 horse-power, and one of the 2–8–2 class with an output of 1,250 horse-power.

The Lotschberg Locomotives.

But the largest and most powerful electric locomotives at present in service in Europe are the interesting machines which have been supplied to work the Lotschberg Railway between Spiez and Brigue, a distance of 48·48 miles, including the tunnel. When this huge undertaking was sanctioned by the Federal Government it was decided to work the tunnel from its inauguration by electric traction, the experience with the Simplon tunnel line having emphasised the advantages of electricity over steam, as already mentioned.

In the case of the Lotschberg Railway, however, the conditions which had to be fulfilled were of a far more exacting character. In order that there should be no uncertainty or delay in working the tunnel directly it was opened for traffic the first section of the line, that from Spiez to Frutigen, 7⅕ miles, which was completed in 1901, was selected as a testing ground

on which the two systems might be run side by side for comparative results, and also to afford some definite data concerning the best system and type of electric locomotive adapted to the heavy conditions which were to be satisfied. This section of the line was suited to the investigations, although the maximum gradient is only 1 in 65, whereas between Frutigen and Kandersteg, the northern portal of the Lotschberg tunnel, the heaviest rise is 1 in 35. For nine years the railway was steam operated, but then it was converted to electric traction on the single-phase alternating current system, the pressure on the contact line being 15,000 volts at 15 cycles per second.

As the business over this high road was certain to equal that passing through the Simplon tunnel, and as heavy trunk railway working was to be expected, the traffic conditions of the St. Gotthard were taken as a basis in determining the electrification of the Lotschberg Railway. The Government laid down the specifications which were to be fulfilled, and these certainly were of no light order. On the St. Gotthard line, where double-heading is practised with the heaviest trains, a load representing 310 tons, exclusive of engines, can be hauled at 22 miles an hour over a maximum grade of 1 in 37. This speed, at least, was to be equalled in electric working, although double-heading was not to be adopted. Accordingly the Government called for the most powerful locomotives that could be designed in accordance with existing knowledge of electric traction. Two locomotives

By permission of Messrs. Brown, Boveri & Co.

THE OLD AND THE NEW ON THE SIMPLON RAILWAY.

Each locomotive develops approximately the same horse-power, but whereas the 4-6-0 steam engine weighs about 110 tons, the electric unit weighs only 62 tons.

were offered, one made by a Swiss company, the Oerlikon Electrical Company of Zurich, and the other by the A.E.G. (General Electric Company) of Berlin.

It was a piquant situation. Each firm has achieved a high reputation in European electrical manufacturing circles, and each was determined to eclipse the other. Accordingly two electric giants were produced, and for two or three years were run neck and neck up and down the track between Spiez and Frutigen, hauling all kinds, lengths, and weights of trains. Careful records were kept of the performances. Neither company spared any effort to show what it could do ; the products of German and Swiss industry were pitted against one another.

At the time the two firms were requested to furnish the most powerful machines they could devise no single-phase locomotive exceeding 1,000 horse-power was in ope
tion in any part of the world. This mea
that considerable pioneering had to
accomplished in the design and constructi
of the machines. Still, the resources of ea
firm were equal to the task. Each suppli
huge magnificent-looking machines, unm
takably bearing the imprint of possessi
great haulage power. At the same ti
each company was under a certain restr
tion which precluded the possibility
carrying the power factor to an extre
degree. According to the internatio
agreement the maximum draw-bar p
mitted is 22,000 pounds.

So far as horse-power is concerned t
Swiss company produced the most power
electric locomotive. Indeed, this engi
No. 121, is the most powerful alternati
current electric locomotive in Europe
present, and certainly exceeds in th

THE MOST POWERFUL ELECTRIC LOCOMOTIVE IN EUROPE.

The 2,000 horse-power 0-12-0 electric locomotive built by the Oerlikon Electrical Company for the Lotschberg Railway.

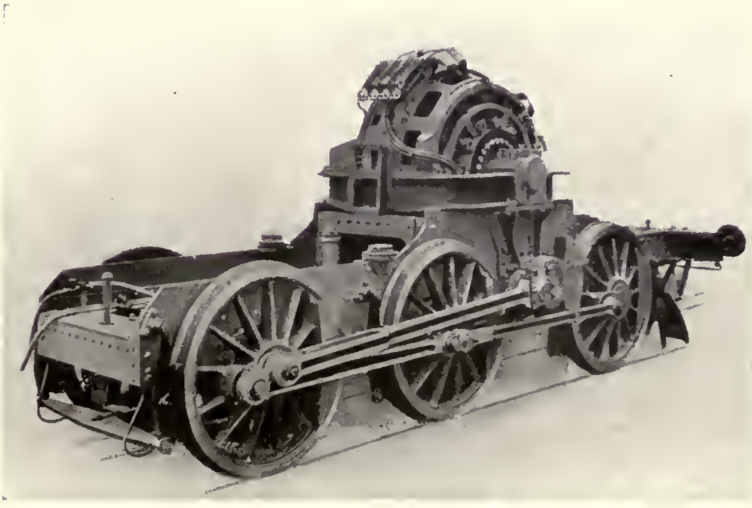
respect any steam locomotive working upon Continental railways. It is of the 0–6–6–0 type, having 12 driving wheels disposed in two groups, each bogie being a complete unit. By this arrangement the whole of the weight of the locomotive—90 tons—is available for adhesion, representing 15 tons per axle. The three pairs of driving wheels of each bogie are coupled, and as the two units are housed in one cab they can be used together. At each end of the locomotive is the driver's station together with control, so that the engine may be driven from either end, the central space being occupied by the transformers and the other electrical accessories. Each motor weighs 9·8 tons, and each transformer 5·5 tons, the total weight of the electrical equipment being 44 tons—practically one-half the weight of the locomotive. The driving wheels have a diameter of 54 inches.

Each motor develops 1,000 horse-power, representing 2,000 horse-power for the complete locomotive, at a speed of 26 miles per hour, at which speed a draw-bar pull of 22,000 pounds is exerted—the maximum permitted by the international agreement. This means that the locomotive can haul a train weighing 500 tons, exclusive of the engine, over a grade of 1 in 66, or a train of 310 tons, exclusive of the engine, up a bank of 1 in 37 at a speed of 26 miles per hour. In order to gain some impression of the significance of this haulage power it may be mentioned that to haul a train of 310 tons over a similar grade on the St. Gotthard Railway at 22 miles an hour—four miles per hour less—requires two locomotives. The combined weight of the latter is approximately 230 tons, or more than $2\frac{1}{2}$ times the weight of the 2,000 horse-power electric locomotive.

The locomotive supplied by the General Electric Company develops 400 horse-power less. It is of the articulated 2–4–4–2 type, there being two sections coupled together. Each carries a motor having an output of 800 horse-power, making 1,600 horse-power for the complete engine, at 25 miles per hour. This enables the locomotive to haul a train weighing 400 tons, exclusive of engine, up a gradient of 1 in 66, or a load of 250 tons, also exclusive of engine, over a gradient of 1 in 37, at 26 miles per hour.

It will thus be seen that the Swiss locomotive with its 400 extra horse-power has the advantage in hauling capacity of 100 tons on the easier, and of 60 tons on the steeper gradient. Taken on the whole it will be admitted that the Swiss manufacturers have acquitted themselves magnificently in what was a difficult undertaking.

As a result of the trials the Oerlikon Company was awarded the contract for 10 locomotives of a similar type. Each engine will be fitted with two 1,250 brake horse-power motors, and be capable of attaining speeds ranging from $31\frac{1}{4}$ to 47 miles per hour.



ONE OF THE SIX-WHEELED BOGIES AND ITS 1,000 HORSE-POWER MOTOR OF THE OERLIKON ELECTRIC LOCOMOTIVE BUILT FOR THE LOTSCHBERG RAILWAY.

THE "EIGHTH WONDER OF THE WORLD."
The Victoria Tubular Bridge, built by Ross and Stephenson, across the St. Lawrence River, to carr
the Grand Trunk Railway from bank to bank.

The Opening-Up of Canada—I

THE ROMANTIC STORY OF THE GRAND TRUNK RAILWAY

THE fifties of the nineteenth century constituted a busy epoch in the development of the railway. British engineers and railway builders were in urgent request the whole world over to plot and lay the highway of steel. In 1850 only fourteen countries were blessed with these transportation facilities, ranging from a handful of 15 miles in Switzerland to 6,621 miles in Great Britain and 9,021 miles in the United States. Not a mile of metal had been laid in South or Central America, south-eastern Europe, India, and the East. Projects were being discussed on every hand, but those capable of grappling with the peculiar requirements of the work were few and far between.

About this time a large firm of British contractors, Peto, Brassey, and Betts, having completed some big undertakings on the European continent, aspired for new worlds to conquer by railway. They h
an immense and valuable plant lying i
with which they could start operatio
anywhere without delay. Moreover, t
possession of this complete equipme
enabled them to tender for work at
favourably competitive figure, inasmuch
it was more expensive to let it lie idle th
to use it.

This situation developed just when
group of daring financiers had decid
upon the railway invasion of British Nor
America. The latter considered this ter
tory to offer tempting attractions, despi
the fact that at that date the populati
of the country was only about 3,100,00
scattered along the shores of the Atlant
the River St. Lawrence as far as La
Ontario, and the narrow strip on the Paci
coast known as British Columbia. So
66 miles of line met the whole requireme
of the country, but it was consider
adequate, because the population depend

upon the water arteries for the movement of traffic.

The first attempt to provide Canada with railway facilities was unpretentious in the extreme. It was a wooden tramway extending a distance of 17·38 miles between La Prairie, opposite Montreal, and St. Johns, on the Richelieu River, so as to offer combined railway and water connection via the Hudson River, Lake Champlain, and Richelieu River with New York. This line was opened for traffic with much jubilation in 1832. But the first winter played such havoc that the wooden rails were torn up during the ensuing spring and replaced by metals. This humble beginning was on a parallel with the famous Stockton and Darlington Railway, the engines and rolling stock being of the most primitive description.

The British financiers evolved an ambitious undertaking, and appeared to have an open field. But conflicting interests soon arose. In 1845 a corporation secured the right to and did build a line from the port of Portland, Maine, to the international boundary, near Norton Mills, Vermont. However, directly it was completed it was taken over by the British financiers for a period of 999 years, and continued from the frontier to Longeuil, on the south bank of the St. Lawrence, near Montreal.

The activity of the British interests prompted other enterprises in different parts of the country with an utter lack of cohesion. Odd lengths of line were built here and there. Realising the drawbacks incidental to this sporadic policy, the British financiers gathered up the isolated sections,

TRAIN EMERGING FROM THE OLD TUBULAR BRIDGE
It carried only a single line.

and consolidated them into a homogeneous whole, at the same time undertaking to connect them together. The act of incorporation was passed by the Legislature in 1852, and the Grand Trunk Railway, as it is called now, came into being.

The railway builders had not been on the ground long when they found that they had under-rated the enormity of the task confronting them. Experience in various parts of Europe, whereupon they had based their constructional estimates, proved useless. They never had been faced previously with similar conditions. The country was inhabited only among the fertile valleys threaded by the St. Lawrence, the settled parts of Nova Scotia, New Brunswick, Quebec, and Ontario. These communities were hemmed in by dense jungle-like primeval forest, the recesses of which were as cold and uninviting in the height of summer as in winter. The dense bush was untraversed save only by narrow, winding, and rough Indian trails. The surveyors slashed their way through solid walls of timber. The work was heart-breaking; progress was exasperatingly slow.

The Surveying Difficulties.

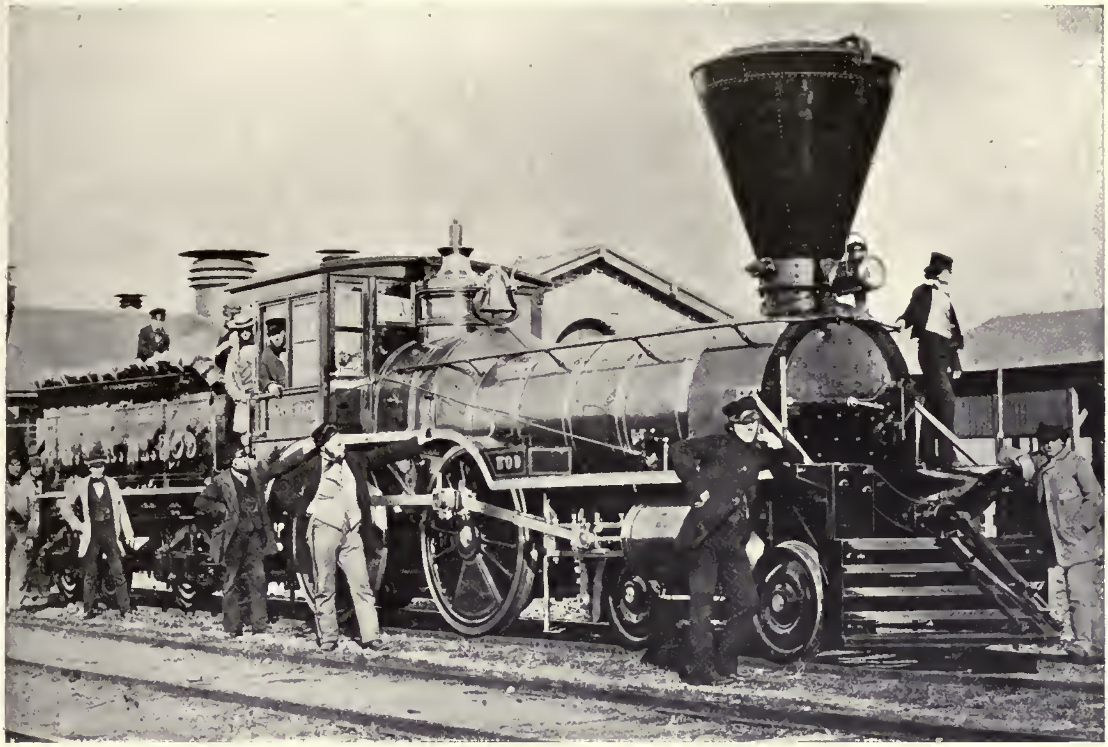
The severe winter, with its marrow-freezing temperature, blinding blizzards, and heavy snowfall, drove all the workers from a silent white tomb to the comparatively gay and attractive settlements. Transport difficulties were enormous, while the feeding of the scattered camps with the most frugal fare taxed the ingenuity of the commissariat department to a supreme degree, and, despite the herculean efforts put forth, the service broke down time after time.

Faced by such pluck-shattering obstacles the builders naturally followed the line of least resistance. They swung down the north bank of the St. Lawrence, and when the waterway opened out into the broad expanse of Lake Ontario, they hugged the latter's northern shore. To-day, while this is a fast channel for through traffic, it suffers from one serious disability which will never be overcome—traffic can be drawn only from one side of the line. Had the road been driven from 10 to 15 miles farther inland, even if it had entailed slashing and hacking through dense forest for every mile of the way, it would have been more profitable in the long run, since the country has become as settled as the South of England, and revenue would have fed the railway from both sides.

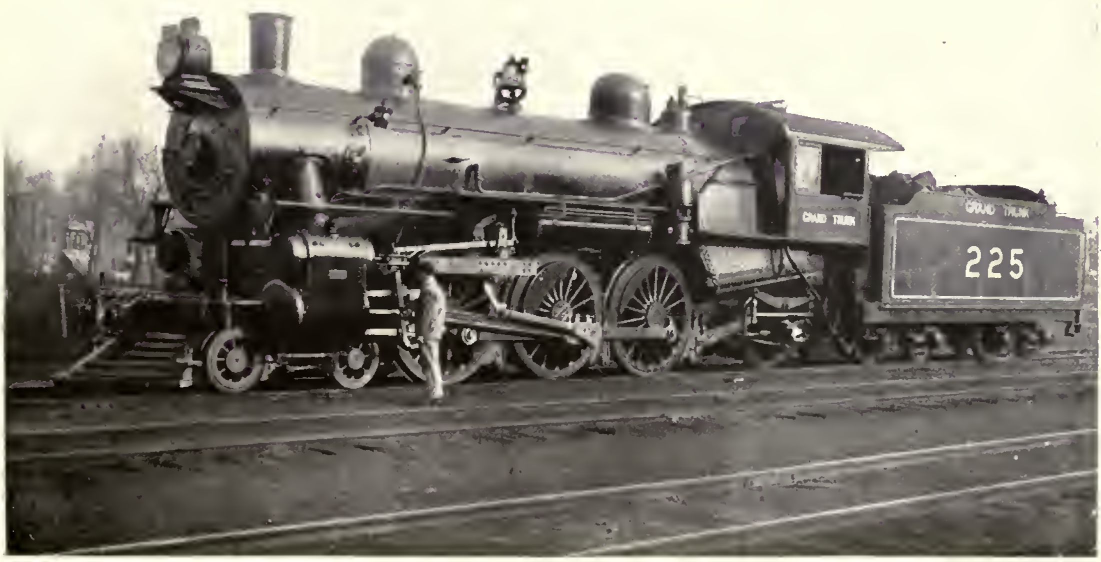
Yet, despite all difficulties, the pioneers prosecuted their task with commendable vigour. The labour problem was acute, but was overcome by attracting workers from the homeland, who, after they had completed their grading work, bought and settled farms with their accumulated wages, and soon attained a position of complete independence if not wealth. Thus the railway builders accomplished two ends by a single stroke. They not only opened the country; they settled it as well. Construction proved exceedingly costly, and although the undertaking was liberally supported by valuable official aid, many British millions were sunk in the work. The railway builders were hit particularly heavily, and when they retired from the scene it is estimated that they left a round million behind them.

The Labour Problem.

When at last the railway was completed between Montreal and the Lakes, through communication with the Atlantic seaboard was interrupted by the St. Lawrence River. Passengers were forced to detrain and cross from bank to bank, when the waterway was open, by a steam ferry. In the winter, when a sheath of ice several feet thick forced the ferry into inactivity, teams and sleighs had to be requisitioned to bridge the gap. A sleigh trip may have possessed certain elements of novelty and exhilaration to visitors, but it was not free from untoward excitement and thrill, especially towards the end of the winter when the ice breaks up. On one occasion a sleigh tooled by one of the expert railway



THE "TREVITHICK." A FAMOUS FOUR WHEEL COUPLED FLYER OF ITS DAY.
Wood was used as fuel, which was stacked in the tender. Note the funnel-shaped smoke-stack.



THE HUGE "PACIFIC" TYPE WHICH HAULS THE "INTERNATIONAL LIMITED" TO-DAY.

drivers started off with its human load. Ere the middle of the river was gained there was a deafening cracking and groaning on all sides. Before those on the sleigh realised the import of the sound the whole mass of ice commenced to move bodily down stream. An immersion seemed imminent, but the driver, alert and vigilant, steered his team dexterously, and at last, when the movement subsided, drove frantically towards the bank, reaching it safely. But the experience proved too terrifying to one of the passengers, who died from exhaustion and fright. It may be mentioned that the ice attains such a thickness on the river as to be able to support a moving train. Indeed, in the movement of freight during the winter the Grand Trunk Railway used to lay down a light track from bank to bank, and run the trains, hauled by a small locomotive, across the ice.

The greatest drawback, however, was experienced every spring and autumn. The ice-floes in the river rendered ferrying precarious, so traffic had to be abandoned for some two or three weeks until the river had cleared or had become frozen over sufficiently to enable the sleighs to venture thereon.

The significance of this interruption was appreciated by the railway from the very first, but how to span the gap was a baffling obstacle. A bridge was certain to be costly and difficult, seeing that at this point the waterway is over a mile in width, deep, and runs swiftly, while the pressure of the vast ice-shoves in the spring is enormous. It was feared that no creation would be able to stand. However, Mr. Alexander Ross, an accomplished engineer, who had achieved a big reputation building railways in Europe, took up the problem. He proposed a massive bridge, built upon the tubular system, such as carries the London and North Western Railway across the Menai Straits to-day. He spent several months inspecting the river and banks, studying the fickleness of the currents and ice runs. He returned to England in 1852 and communicated his proposals to Robert Stephenson. The latter extended his approval and congratulated the engineer upon his daring and skill. When Ross's designs became known they were attacked vehemently in certain quarters, especially by American interests who aspired to complete the work, but Stephenson supported his colleague whole-heartedly, and the work was commenced.

THE VICTORIA JUBILEE BRIDGE, MONTREAL, SHOWING THE NEW SUPERSTRUCTURE.
It was built around the tubular bridge, so that traffic was not stopped. The present bridge carries a double track, electric tramway, roads, and pavements.

The first stone was laid on July 22nd, 1854, and Ross haunted the scene day and night until the bridge was completed on November 24th, 1859. Surprises were sprung upon him and his collaborators at every turn, but every difficulty was subjugated as it developed, and with very little delay to the work. No chances were taken. The piers were built upon ample lines, and carried well down into the river bed to withstand a current of some 7 miles per hour and the terrifying ice-shoves which are set up each spring. The engineer was handicapped somewhat by the short period of the working season, which averaged only some twenty-six weeks per year, until the superstructure could be taken in hand. Every available man was crowded on, about 3,000 labourers finding employment when the task was in full swing.

PULLMAN DRAWING-ROOM CAR ON THE "INTERNATIONAL LIMITED."

The setting of the iron-tube, in which the metals were laid from bank to bank, was the most exacting task. The tunnel was 6,592 feet long, by 16 feet wide, and 18 feet high, divided into twenty-five spans, and the toilers were called upon to handle 9,044 tons of metal. By the time the last of the 2,250,000 rivets had been driven well and truly home on August 25th, 1860, by His Majesty King Edward VII., then Prince of Wales, £1,300,000 had been spent, an unexpected result, as the expenditure was £100,000 less than the estimated price.

The Victoria Tubular Bridge, as it was called, was reckoned to be the "Eighth Wonder of the World." So soundly was it built that it defied the caprices of the St. Lawrence for nearly forty years. It was a huge metal bore carrying a single track, and as the railway business grew it became

taxed and taxed until it carried 100 trains a day. The working of the bridge was brought to its limit; not another train a day could be squeezed in. Only one train could be on the bridge at a time, and this bottle-neck set up heavy traffic congestion. Moreover, the engines and trains so grew in weight that apprehensions arose concerning the safety of the structure.

Accordingly, in the early 'nineties, the question arose as to whether the time had not arrived when the Ross and Stephenson bridge should be superseded by a structure more in accordance with the times. The point was: "What is the most economical means to achieve the desired end?" The subject was discussed earnestly; finally it was decided that the easiest, simplest, and cheapest means of meeting the situation was to provide a new superstructure, making the conversion upon piecemeal lines under traffic conditions. The piers were enlarged so as to take a new and wider open bridge to accommodate two sets of metals, a road for trams as well as highways for vehicular and pedestrian traffic.

How the Bridge was Rebuilt.

The piers were examined and found to have been built so strongly that they required no additional reinforcing; the new masonry to carry the widening merely was added to the old. Work was commenced in October, 1897. Each new span was built around the existing tube, and when completed and ready for setting in position, the old span was cut away from its supports and then withdrawn. Work went forward uninterruptedly, span by span, although for two months not a stroke could be done owing to the severity of the winter of 1897–8. Extreme precautions had to be observed so as to reduce interference with traffic to the minimum, but this was fulfilled so completely that during the eight months construction was in progress the aggregate period for which the bridge was closed amounted only to 20 hours, the longest single spell being two hours' duration.

The new bridge is more than twice t[he] weight of its predecessor, containing 22,0[00] tons of steel. It is 66 feet 8 inches in width, and varies from 40 to 60 feet in height, while it cost £400,000. The present link [of] communication, known as the Victo[ria] Jubilee Bridge, with its double track, [is] likely to meet all requirements of the ra[il]way for many years to come, its capaci[ty] being practically unlimited in conjuncti[on] with the electric block system, permitti[ng] some three trains to be on each road of t[he] bridge simultaneously.

The N[ew] Bridge

When the British builders laid t[he] original stretch of railway, constituti[ng] the foundation of the Grand Trunk system, the broad gauge of 5 feet 6 inches was adopted. But later railways in other pa[rts] of the Eastern provinces preferred t[he] Stephenson gauge of 4 feet 8½ inche[s]. Canada accordingly had its "Battle [of] the Gauges," even as did Great Britai[n]. Sir Henry Tyler, when he assumed t[he] presidential chair of the undertaking, [re]commended in 1867 that the 5 feet 6 inch[es] should be adopted as the standard for t[he] Grand Trunk, and that a purchased su[b]sidiary stretch of 60 miles, running fro[m] Detroit to Port Huron, which had be[en] built on the narrower, should be convert[ed] to the broader, gauge. However, t[he] Stephenson gauge triumphed on the Nor[th] American continent, so that, unlike t[he] Great Western Railway at home, the Gra[nd] Trunk bowed to the inevitable witho[ut] delay. In 1874 the broad gauge w[as] abandoned in favour of that of 4 feet [8½] inches.

"Battle of the Gauge[s]"

While Sir Henry Tyler manifested sho[rt]sightedness in respect of the gauge, [he] was exceptionally perspicacious in a[n]other respect. Chicago at that time was [a] healthy growing town of 200,000 peop[le]. Tyler advocated pushing the Grand Tru[nk]

metals into the budding metropolis of the Middle West with all possible speed. The movement was opposed, but he gained the day, and the rails were carried into Chicago. This was a smart display of enterprise, as subsequent events have proved conclusively, because the steel highway between Montreal and the "Windy City" constitutes the busiest railway artery in Canada, over which flows the commerce of two powerful nations. The growth of Montreal as a shipping point during the summer is developing this traffic in an amazing manner, as Chicago and its flourishing industrial environs are provided with an additional outlet to Europe.

COMBINED PULLMAN AND SLEEPER.
The lower berths are made up between each facing pair of seats. The upper berths are let down like shelves from the angle ceiling.

The original highway between these two points was a single track, which, comparatively speaking, was laid as cheaply as possible, making curves to avoid obstacles, and with heavy banks which, as traffic grew, hindered easy, cheap, and quick movement severely. For some years the company tolerated these drawbacks, with the result that it was outstripped by more energetic rivals which had arisen; indeed, its very existence was threatened. The railway became a by-word of reproach throughout Canada and the United States, and was avoided by all except those who either had to take it or walk. Disaster appeared to be imminent; dividends had vanished; traffic had shrunk to negligible proportions.

At this juncture energetic spirits secured the reins of control, and the process of

CANADA'S CRACK TRAIN, "THE INTERNATIONAL LIMITED," MAK

The 842 miles are cov

MILES AN HOUR BETWEEN MONTREAL AND CHICAGO.
22 hours, including stops.

rejuvenation was undertaken regardless of expense. The whole of the trunk road between Montreal and Chicago was torn up, straightened, flattened, and many superfluous miles were cut out. Moreover, it was double-tracked from end to end, the length of this stretch, representing 842 miles, rendering it one of the longest double-tracked railways in the world. No less than $16,606,445, or over £3,320,000, were expended upon this scheme of modernisation, and, as events have proved, this courageous policy, worthy of Harriman, has turned out the wisest and most profitable development recorded in Canadian railway history.

The result of this wise move was felt instantly. Traffic congestion was removed, and the commercial centres in the Middle West, obtaining quicker dispatch, embraced this route for their shipments. Passenger traffic advanced likewise by leaps and bounds, and as this became more and more imposing no effort was spared to foster it. This policy culminated in the introduction of the "International Limited," which to-day is Canada's crack train, both in luxurious appointment and speed, covering the 842 miles between Montreal and Chicago in 22 hours. To-day, the Grand Trunk line between Montreal and Chicago is the busiest steel highway in the Dominion, and one of the most heavily patronised by freight and passenger upon the North American continent.

While overhauling was in progress the railway also pursued the wise action of buying out rivals. Odd short lengths of line here and there were acquired and consolidated into the parent system. Thus some of the most relentless competition was eliminated, and a huge system, now aggregating 5,300 miles, forming a gigantic steel web over the whole of Southern Ontario has been spun.

CARILLON AND GRANVILLE RAILWAY TRAIN.
The oldest train in America, with the old famous "Birkenhead" locomotive.

Photograph by Wehrli, Kilchberg, Zurich.

THE LOWER TERMINUS OF THE JUNGFRAU RAILWAY AT KLEINE SCHIEDEGG.

To the Eternal Snows by Rail

HOW THE JUNGFRAU, THE GIANT OF THE BERNESE OBERLAND, HAS BEEN CONQUERED BY THE STEEL HIGHWAY

HERR ADOLPH GUYER ZELLER was an enterprising manufacturer of Zurich. The claims of business did not afford him many opportunities for relaxation, but in August, 1893, he seized the opportunity to snatch a few days' holiday with his daughter in the Bernese Oberland. In the manner of every visitor, his itinerary included the ascent of the Schildhorn, and the arduousness of climbing even the easiest of mountains afoot was brought home to him vividly.

While descending the mountain and enjoying the vista of glacier-top and ragged snow-clad crest forming the frowning rampart from which the heads of the Jungfrau, Mönch, and Eigerjoch tower above the deep ravine of the narrow White Lütschine, his eyes became arrested by a trailing film of smoke which curled higher and higher up the side of the mountain wall. The sight of that filmy trail swung his thoughts from romance and idleness into the stern rut of business and commerce. The black streak which he saw emanated from the little locomotive which was puffing, snort-

ing, and straining for all it was worth to lift one or two carriages laden with visitors over the narrow track of steel which had been laid from Lauterbrunnen through the Kleine Schiedegg Pass. He watched the combing wreaths for some minutes and then proceeded to his hotel, thinking hard and speaking but little.

When he returned to Zurich a few days later he sought out some of his financial friends, and in conclave out-

A Startling Proposal.

lined a scheme which was at the back of his mind. His companions listened intently, but finally punctuated his conversation with the ejaculatory comments, "Impossible!" "Quite impracticable!" "Kochlin, Trautweiler, and Locher had the same idea, but gave it up!" The manufacturer ignored their remarks, and asserted more vigorously than ever that his idea was feasible.

The astonishment of his friends was not surprising, for Herr Guyer-Zeller's proposal certainly was startling. It was nothing more nor less than to carry a railway to the summit of the Jungfrau. The idea was not novel by any means, because at different times a similar project had been outlined by Kochlin, Trautweiler, and Locher, but they had been foiled. The Zurich manufacturer, as a result of his climb of the Schildhorn, had grasped in a moment how he could succeed where those before him had failed. They proposed to take the railway through the White Lütschine valley, which he deemed to be madly impracticable. He pointed out that the Wengernalp Railway started from Lauterbrunnen and climbed to Kleine Schiedegg at 6,770 feet. That was the obvious route to the Jungfrau summit, and by starting from Kleine Schiedegg it would be necessary to overcome only another round 9,000 feet, as the Jungfrau rises to a height of 13,671 feet above sea level.

Although his friends were somewhat sceptical as to the feasibility of the route which Guyer-Zeller suggested, they decided to have preliminary surveys made. Fortl with a small party was sent out to discove a surface and tunnel line from Klein Schiedegg to the topmost height of th famous peak. The plotters had a perilou time. Scrambling among the ragged flank of this mountain, with its fearsome crag deep rifts and glaciers, dodging avalanch and rock-slide, was exciting and dangerou The engineers sought the finest guides o the country—men who knew the moun tains intimately—in order to be guide through the fastnesses. The promoter o the scheme had realised the impossibility o a straight line between the two points, a the grades would be too steep, so he ha suggested that the engineers should searc for an alignment giving a maximum ris of 1 in 4. The railway plotters were ou for several months, but when they returne they had with them a location which coin cided with Guyer-Zeller's instructions.

The scheme was investigated again, mor minutely. Although constructional wor in the upper sections was certain to be highly expensive owing to the extent of the tun-

Preliminar Work.

nelling, the financiers decided to father th project. The financial support was whippe up, the scheme was carried to the Swis legislature, and received the necessar official sanction. Then the preliminar preparations were hurried forward. On base was established at Lauterbrunnen and another at Kleine Schiedegg. Th Wengernalp Railway was to be used as supply line, but there was one difficulty During the tourist season the capacity o the little line was so taxed that it coul not be used for the transit of material fo the new project. Accordingly, immens quantities of stores were brought up t Lauterbrunnen. sent up the mountain b rail as opportunities occurred, and wer cached at several convenient points forwar of Kleine Schiedegg.

At first the going is easy, as, startin from Schiedegg, the line follows the Schie

degg Pass to the Eiger, through a narrow gulch which divides the White from the Black Lütschine. The coming of the railway has wrought a wonderful change at Scheidegg. Twenty years ago there was not a house for miles around. To-day there are two fine hotels, flanked by shops and other dwellings, while the railway depot is a busy centre of animation. The Wengernalp Railway, since the first sections of the Jungfrau road were opened, has developed wonderfully, and it is no uncommon circumstance for 3,000 people to be brought up from Lauterbrunnen and Grindelwald in a single day.

The Eiger Glacier station is 2,187 yards beyond Kleine Scheidegg, and in this distance 954 feet in altitude are overcome, giving a grade of 13·17 per cent. At the present moment this is the constructional base for the last sections of the railway, because farther forward there are no available sites for shops, provision stores, and other requirements. The arrangements in this connection have to be planned with extreme care; nothing must be omitted, because during the winter, when construction is in full swing, the upper parts of the railway are isolated completely from the lower stations. Both the Wengernalp and the Jungfrau Railways are compelled to shut down in October, owing to the heavy falls of snow which block the tracks, burying them in places to a depth of 30 feet or more. The supplies are brought up in the late autumn, when the tourist traffic has eased up somewhat. The stocks required for a winter's work comprise twenty-five car loads, each of six tons—150 tons in all. The constructional

Photograph by Wehrli, Kilchberg, Zurich.

THE JUNGFRAU RAILWAY TRAIN.

Showing locomotive with two coaches and the overhead equipment.

army is somewhat small in comparison with other enterprises, numbering from 100 to 150 men; but this is due to the fact that more cannot be employed, owing to the confined character of the working area. The tunnels can only be driven from one end, and the face is so small that only a handful of men can ply the drills simultaneously.

Work at the Eiger Glacier level, although it lies at an elevation of only 7,634 feet, is no light undertaking, and it imposes a severe strain upon the men, not only from the rarefied air, but from the extreme cold. In winter the temperature falls to 54° below freezing point, but the air is dry, so that the full effect of the low temperature is not experienced so keenly as in the damp lowlands, while in January and February the weather mid-day is so warm that the workmen often dine in the open air. At this point there is a central baker where all the bread for the working gan is prepared and sent forward as desire while the provisions are almost exclusive of the preserved variety, it being impossib except at rare intervals to get down in the valleys. The water problem is t most acute. Not a drop of fresh wat is to be obtained for love or money, as a the creeks and torrents are frozen sol from November to May. Every ounce ha to be obtained by melting the snow, an when it is remembered that fourte quarts of snow yield only one quart water, and this commodity is required f a hundred and one purposes, the task the contractors to meet this need may imagined. After many experiments we made an ingenious electrical melting sy tem was perfected, and in this mann ample supplies can be secured.

Photograph by Wehrli, Kilchberg, Zurich

VIEW FROM A WINDOW AT THE EISMEER STATION SHOWING THE JUNGFRAUJOCH.


Photograph by Wehr i, Kilchberg, Zurich.
EISMEER STATION FROM THE OUTSIDE, SHOWING WINDOWS TWENTY FEET WIDE CUT IN THE ROCK.

The snowfall in this region is terrific. It is by no means unusual for the posts and conductors of the overhead electrical equipment to be buried out of sight. The houses of the workmen are piled up to a height above the ground floor windows, demanding the use of artificial light in the lower rooms, while the men have to drive tunnels through the banks to enter their houses. There is a telephone in operation between the depot and the valley below, but the heavy snowfall repeatedly causes interruptions by breaking the wires. Then the electrical staff has to turn out and without delay repair the breaches. Some of the engineers have become expert on ski, and when a breakdown in communication occurs, or an urgent call for aid through accident is encountered, they embark upon a hazardous journey, often through a driving blizzard, to Wengernalp, the nearest hamlet. But the snow brings another and more formidable peril. This is the avalanche, which assumes more terrible proportions with the heaviest snowfalls. These slides are of unpleasant frequency, and come tumbling down the Eiger slopes with fiendish velocity. More than once the little colony has been overwhelmed by an avalanche measuring 200 yards in length by 250 yards wide and 300 feet deep. Cutting trenches and tunnels through such an accumulation is no light task. Fortunately, owing to the purity of the air, disease and illness are practically unknown. Accident is the only thing to be feared, and if the injuries or sickness are such as to be beyond the resources of the camp and its hospital, a doctor is summoned from the nearest village by telephone, the engineers and overseers, who have been through a course of special instruction, rendering first-aid until his arrival. The seriously injured are then taken as carefully as possible down the mountain-side and transported to Interlaken for treatment.

Snow Dangers.

Between Schiedegg and Eiger Glacier there is one tunnel 265 feet in length, but as it runs through what is called "dogger," a friable schist, boring was somewhat dangerous, while masonry lining became requisite. Outside Eiger Glacier station, however, what is known as "hochgebirgskalk," a hard and tenacious limestone, is first encountered. The rock being intensely hard, no masonry lining is required for tunnels through this material.

The Electric Drill.

Boring was found to be somewhat difficult, inasmuch as the engineers have been restricted in the type of drills for the work. The Brandt hydraulic rock drill, though keenly desired, was impossible, owing to the deficiency of water, while the gradient, which is 25 per cent., was an insuperable obstacle. Under these circumstances it became necessary to use a drill which can be handled more conveniently, is readily dismounted, and easy to move from point to point. Electric drills were found to be the most satisfactory, and although many types were tested, the Siemens and Halske tool was found to be the best adapted for the work, and has been in exclusive use since 1902. These drills are easy to handle, and about 400 blows per minute are given with a force of about $1\frac{1}{2}$ horse-power per machine. The tunnel above Eiger Glacier station is 6 miles in length, and has a semicircular crown in section, the extreme height being $14\frac{1}{2}$ feet from track level, with a maximum width of 10 feet. The tunnel is lighted throughout, and its negotiation occupies twenty minutes.

A Wonderful Station.

The tunnel leads to Eigerwand station, which is part of the tunnel itself, widened out to form a huge hall of arched section. As a station it is unique, inasmuch as it is entirely in the heart of the mountain. A lateral gallery leads from the platform to the station proper, this approach, hewn out of the rock, being 20 feet wide by 26 feet long. The station has a superficial area of 2,370 square feet, the roof

being supported by solid pillars of rock left untouched, varying from 10 to 16 feet in thickness. On the north side the wall of the mountain has been pierced by huge apertures 20 feet wide, affording a magnificent view over the field of mountain peaks and glaciers.

One feature of the concession, which has assisted this great enterprise very pronouncedly, was the permission to build the line in sections, and throw them open to the public as they were completed. Thus the line has been revenue-earning from the completion of the first stage to Rötstock, a temporary station opened between Eiger Glacier and Eigerwand on August 2nd, 1899. In that short season over 22,000 passengers were carried to the railhead, while in 1903, when Eigerwand was brought into the service, the number of passengers rose to nearly 30,000 in the season.

Still in tunnel, the railway climbs another 960 feet in the course of 1,420 yards to reach Eismeer station. In gaining this point at an altitude of 10,370 feet the railway has to round the Eiger, the lower station being on the north and the upper station on the south side. This has necessitated the introduction of a curve of 656 feet radius. Eismeer station is a counterpart of that at Eigerwand, being hollowed out of the solid rock. The railroad tunnel proper, however, is of greater width, being of 30 feet, to provide a double track, as here the up and down trains pass. Although the station is within the mountain, the tourist is able to gain the exterior snow, glaciers, and couloirs by means of a subway, having a gradient of 33 per cent., hewn out of the rock, to emerge 130 feet below the station on to the glacier.

Photograph by Wehrli, Kilchberg, Zurich.

GENERAL VIEW OF THE TRACK, SHOWING CENTRAL RACK-RAIL.

But it is the last section which marks the crowning achievement of the constructional engineer's wonderful skill. Herr Guyer-Zeller, when he outlined his idea, stated that his objective was the top of the Jungfrau, so that the passenger might be able to step out of the train and stand on the very highest point of this lofty giant to gaze upon a most inspiring view. The engineers, though deprived of his further stimulating influence, owing to inexorable Death having overtaken him, are fulfilling the dreamer's scheme to the letter. Directly

Photograph by Wehrli, Kilchberg, Zurich.

THE APPROACH TO EIGERWAND STATION, SHOWING WINDOW.
The station and approaches are hewn out of the solid rock.

Eismeer station was opened they attacked the last lap to the Jungfraujoch. It was realised as being a tough piece of work, both because it was to be through solid rock and because of the rarefied atmosphere, which has tried the highly skilled workmen sorely. It was a pretty stiff proposition, since it involved driving a tunnel for 3,470 yards at an altitude of over 10,500 feet through a great ridge of rock and ice which connects the peaks of the Mönch and Jungfrau. But after some six winters' hard work the ridge was pierced, the rock-hogs emerging into daylight once more at an altitude of 11,342 feet, where the Jungfraujoch station has been planted. The station proper is 190 feet from the platform, the latter being in a cavern, while the former is on a massive plinth of a towering peak which has been levelled off. The station, like those in the mountain chain at Eigerwand and Eismeer, is unique in its way, and will be a popular resort with travellers when completed. It is being built of solid stone to resist the ravages of the avalanche, fitted on all sides with huge plate-glass windows, from which a panorama over the whole glacial field of Switzerland is unfolded. In fact, it is safe to assert that there is not another view-point in Europe accessible to the ordinary traveller which offers such a spectacle.

The engineers now are wrestling with the final 2,272 feet. It cannot be completed entirely by railroad, as the distance is too short to secure a grade of 25 per cent., so a tunnel is being continued to Jungfrau station at this grade to reach a level of 13,432 feet. The final 240 feet to the peak of the mountain itself are to be overcome by an elevator, emerging from which the traveller will be poised at an elevation of 13,672 feet.

The railway is operated throughout its

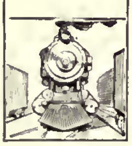
length by electricity. The current is drawn at 5,000 volts from the power house fed by the wild Trümmelbach. The current is led through two heavy overhead copper conductors. The track itself is the latest devised by M. Emile Strüb, of Zurich, which now is adopted throughout Switzerland in connection with mountain railways, with the rack-rail disposed centrally between the two adhesion metals. The electric locomotives themselves are claimed to be the finest mountain engines in the world, and they have been fitted with every possible device to prevent running away. Whether ascending or descending, they cannot possibly exceed a speed of 5¼ miles per hour. Should an attempt be made to go beyond this velocity, there is an automatic brake, over which the engineer has no control whatever, which comes into action and stops the train. But there is the chance that the electric supply might break down, in which event the above brake is driven differently. The motors on the train become generators to operate this brake, the current being produced by the descending weight of the locomotive. Thus it is absolutely impossible for a train to get away unless everything fails, which is a remote contingency. Neither can the train mount the track. On the front axle of each locomotive is a powerful gripper, which clutches the rack, so that the engine cannot rise. The frame of each engine rests upon two axle carriers, and each axle is fitted with a 150 horse-power motor running at 760 revolutions per minute. The current is drawn from the overhead wires through four trolleys, two per phase, while the negative current is taken up from the rails through the frame of the engine. Each train is composed of one locomotive and two carriages, each of the latter seating forty passengers. The rolling stock is of the corridor pattern, with large glazed windows, and fitted with every convenience.

THE JUNGFRAUJOCH STATION, 11,342 FEET ABOVE SEA LEVEL.
Showing lighted tunnel to the exterior of the ridge.

BUILDING A SNOW-SHED ON THE LOFOTEN RAILWAY, SCANDINAVIA.

Combating the Avalanche

HOW THE RAILWAYS PROTECT THEIR LINES FROM THE RAVAGES OF SNOW WITH COSTLY SNOW-SHEDS



SNOW probably is the most implacable foe against which the railway engineer possibly can be pitted. Fog will throw traffic all sixes and sevens, and will cause exasperating delays by demanding slow, cautious movement, but snow often ties up a railway completely, bringing about total suspension of the services maybe for days.

Accordingly the railway engineer has come to regard the snow fiend with every respect, and has spared no effort to devise ways and means of circumventing its ravages. It is not the blizzard which he dreads so much, though at times when the snow drifts and scuds over the ground it brings traffic to a standstill by piling big white banks in the cuttings through which a locomotive cannot plough its way, but the avalanche is his terror. It not only fills up his cuttings with snow, rock, timber, and other debris, but, unless precautions are adopted to mitigate its effects, is able to knock the permanent way out of all recognition, demanding not only clearing

THE CONQUEST OF THE AVALANCHE.

To secure protection against the destructive effects of snow slides at exposed places, massive timber, masonry, or ferro-concrete sheds are built over the line.

but reconstruction of the track before the trains can be run.

In districts where snow wages its relentless warfare against human handiwork with seasonal regularity, the engineer practises the precept that "Prevention is better than cure." He makes no attempt to arrest the progress of the snow movements, but lets them go their way unimpeded, merely striving to divert them clear of the track, so as to expend their destructive energy harmlessly at some other place.

The C.P.R. Snow-sheds.

The Canadian Pacific Railway always has suffered severely from the buffetings of the avalanche, or "snow-slide," as it is called locally. These assaults are experienced particularly in the mountains upon the 140 miles between Sicamous Junction and Golden.

The mountain section of this railway traverses five—*through* two, and *over* three—mountain ranges. Coming eastwards from the Pacific the line, following the Fraser and Thompson Rivers, passes through the Coast and Cascade Ranges at a comparatively low level. At no point does the train rise to an elevation exceeding 1,200 feet above the sea. In these ranges a very heavy rainfall, varying from 70 to 105 inches per annum, is encountered. On the other hand there is almost a total absence of snow.

Continuing eastwards the railway passes over three other ranges in rapid succession. These are respectively the Gold Range, the Selkirk Range, and the Main Range of the Rocky Mountains. As a matter of fact the two first named ramparts are subsidiaries of the great North American mountain system, but the Main Range of the Rockies is so-called in order to distinguish it from the others. In these three ranges the railway attains considerably higher elevations than upon any other part of the mountain section, the summits of the passes being respectively 1,900, 4,300, and 5,300 feet. Here the annual snowfall is very heavy. On the railway the average fall is 25 feet in the Gold Range, 35 feet in the Selkirks, and from 14 to 15 feet in the Rockies. Thus it will be seen that the Selkirks receive the heaviest precipitation, and the 35 feet average often has been exceeded. The heaviest maximum snowfall recorded is 45 feet 7 inches, but there is an unconfirmed report that in one winter the fall reached 56 feet!

Snow in the Rockies.

The reason why the snowfall is so heavy in the Gold and Selkirk ranges is because these are the first high mountains encountered by the moisture-saturated clouds which drift eastwards from the Pacific Ocean. These high ridges intercept the cloud movements, with the result that the moisture with which they are laden becomes precipitated—rain in summer and snow in winter. By the time the air currents have reached the Main Range of the Rocky Mountains they have been deprived of the greater part of their moisture, and thus, being comparatively dry, the snowfall on the last named range is much lighter, although the ridge is approximately 2,000 feet higher than the other ranges to the west.

Therefore it will be seen that, while there is a considerable volume of snow to be handled in both the main and its two subsidiary ranges lying immediately to the west, the snow-fighting efforts to keep the line clear have to be concentrated upon that section of the railway extending through the Selkirks, with the Gold Range as a good second.

During the very first winter, when the railway builders were toiling among the crags and precipices of the Selkirks, laying the bond of steel, the severity of the snow movements was driven home upon the Canadian Pacific Railway engineers very compellingly. The permanent way is practically side-hill excavation through the range. As the grade runs at right angles

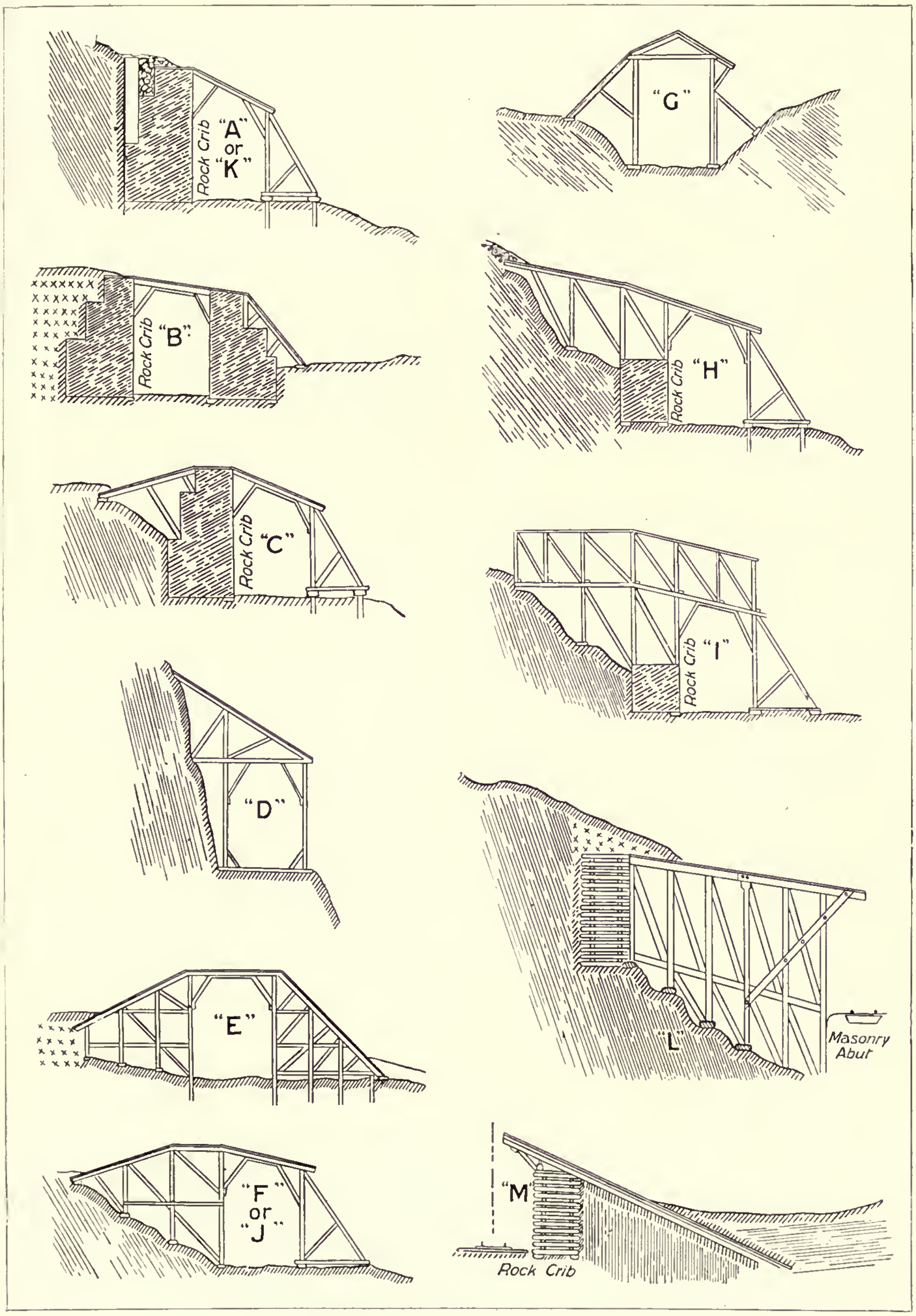
to the paths of the snow-slides it is exposed to the full brunt of any movements. Accidents innumerable have been caused through the snow, but, owing to the vigilance and unremitting care displayed by the railway officials, casualties have been few, although now and again there has been a heartrending calamity. The railway, however, suffers more heavily from the delays which are set up by the line becoming choked with snow and debris. Thus the problem has been to reduce this adverse factor to the very smallest degree.

INTERIOR OF SNOW-SHED ON THE CANADIAN PACIFIC RAILWAY.

Snow-shedding was the obvious measure of protection, but it was admitted that such works would have to be of a remarkably massive design and solid construction to withstand the buffeting of the snow movements. The mountain slopes are steep and are littered with boulders and masses of huge rock, as well as being thickly clothed with timber. When the snow moves in a mass, and commences its downward descent, it gathers an immense accumulation of timber and rock, which it hurls downwards with terrific force. It is doubtful whether any but those who are brought face to face with these slides can form any idea of the enormous force they exert. Few engineers have acquired such knowledge of this phenomenon and its results as Mr. J. P. Forde, who for many years was engineer-in-charge of the mountain division of the Canadian Pacific Railway, and who, perforcedly, was brought into intimate contact with the snow movements and how to avoid or to mitigate their devastating caprices.

This engineer, to whom I am indebted for the accompanying information concerning this phase of operations upon the first Canadian transcontinental railway, narrated that on one occasion a slide was timed in its descent. After attaining its full dimensions it travelled for a distance of 2,500 feet down the steep hill-side in thirty seconds. When it had come to rest it was measured, and was found to average 500 feet in width, 40 feet in depth, and 2,000 feet in length. As the snow at the time was packed closely it weighed about 50 pounds per cubic foot. Consequently, when the slide attained its maximum velocity it was travelling at a speed exceeding 60 miles per hour, while the total weight of the moving mass of snow, ice, rock, earth, timber, and so forth was *about* 1,000,000 *tons!*

Is it surprising under these circumstances



DIFFERENT TYPES OF SNOW-SHEDS.

that huge trees are torn up like weeds, and snapped in twain like carrots, or that huge pieces of rock are wrenched from the mountain side and tossed about like pebbles? At the same time one can appreciate the unequal odds against which the engineer is pitted, and the ingenuity he is compelled to display in order to protect the slender link of communication from annihilation. Of course, it would be impossible to build any kind of structure capable of withstanding the impact of such a slide as that referred to. It is only possible to design the protective works in such a way as to achieve the desired end without offering any resistance to the movement.

How the Sheds are Planned.

The sheds are invariably built of timber, although recently ferro-concrete has been brought into service as a constructional material, as described elsewhere. Remarkable ingenuity and skill are displayed in evolving the type of shed best adapted to the prevailing conditions. No one type possibly could meet every situation. Thus the sheds are not only of great variety, but a single shed even may be of a composite character, the variations occurring at different points to secure the desired result to the best advantage.

The main idea in carrying out work of this nature is to plan the shed so that it fits as closely as possible to the ground where it is built. Accordingly the structure may be of apparent simple and light design ; on the other hand it may appear to be intricate and unwarrantably heavy. The grade being laid on a shelf excavated out of the mountain side, the engineer strives to restore the former contour of the hill side, so as to carry the debris harmlessly over and clear of the line. If this is impracticable, then he designs his roof in such a manner that it offers the least resistance to the moving mass. Moreover, he studies the character of the snow-slide and its accustomed path attentively, modifying his details of design according to the velocities of the avalanche, dimensions, weights, and composition. In some places the length of travel is comparatively short, the bulk small, and for the most part comprising snow only. In another the descent will be sharp, the travelling speeds very high, with timber, loose rock, and detritus looming largely in the mass, increasing its weight and dimensions. Also he takes into consideration the contour of the ground on either side of the line, since if it rises up again on the lower side, he has to bear in mind the possibility of the slide falling back after it has passed over the shed.

Types of Sheds.

In the diagrams on page 371 different types of sheds are illustrated, and these are capable of modification to an indefinite degree. The " A " or " K " type is perhaps the most familiar from pictorial representation. Here, on the mountain side of the line, an immense rock crib is built, balks of timber dovetailed, bolted together, and fitted to the wall, being packed and loaded with massive pieces of rock, while the roof is finished off to the slope of the mountain so as to form a sharp continuation thereof. On the opposite side the uprights comprise huge posts spaced closely together, heavily braced and strutted, to secure rigidity and strength for the roof. By giving the latter a sharp fall, the moving mass can be thrown clear of the structure on the lower side, to tumble into the valley below. In the " B " type the rock cribwork is placed on either side, forming virtually a wooden tunnel for the line. In this form the protective wall on the lower side serves to prevent the debris damming back into the grade as might occur owing to the ground not falling away. In " C," as the track runs through a shallow cutting it is necessary to build up the slope formation on the mountain side so as to lift the avalanche almost imperceptibly over the track. The " E " and " F " or " J " types are modifications of this design, and are generally introduced at such places where,

owing to the configuration of the ground, the slide becomes somewhat spent before reaching the line. Type "D" is somewhat simpler, being adapted to those points where the line skirts a precipice, and where it is probable that the avalanche invariably attains a high velocity, so that it clears the track quickly, instead of dropping directly on to it. Type "G" is useful where small pure snow movements are likely to be experienced, or where, owing to the open character of the location, the snow is likely to drift heavily. The "H," "I," and "L" types are more elaborate, and are modifications of one another. There is a double roof, with intervening rafts and bracing. These are used at points where the slides are apt to bring down masses of rock and timber. The final type, "M," is a simple means of throwing the snow clear of the line. On the mountain side the heavy rock crib is built up to support massive balks which are laid so as to point upward over the track. The lower ends of these timbers are buried, and the ground shaped to form a hollow. The descending snow rushes into the depression and up the inclined plane to fly into the air and to fall clear of the track, the clearance varying with the velocity of the avalanche. This is the system which has been adopted extensively, only in masonry, upon the Lotschberg Railway.

Fire Dangers.

The snow-shed is a costly protection. The more elaborate and heavy types run up to as much as £40,000 per mile to build. In one or two instances this figure has been exceeded, especially in places where the timber has had to be hauled from a distance. While the engineer by snow-shedding protects the line from one danger he invites another. This is fire. A spark from a locomotive may set the structure ablaze, and, once the flames secure a strong hold, destruction of the work is certain, since the shed acts as a huge flue. But the forest fire is dreaded more than the spark from the passing engine. Among the Selkirks this terror of the forest wreaks widespread havoc every year. In order to reduce the losses from this cause the sheds are built in short sections, with long gaps between, so that the possibility of the flames "jumping" is reduced. Incidentally it is the forest fires which accentuate the severity of the avalanche. The trees come toppling down as their roots are burned away, or are scorched into lifelessness, so that they succumb readily to such an attack as snow movements or even of the wind. The sides of the mountains thus become littered with gaunt trunks, maybe one hundred feet in length, and when these are picked up by the slide and hurled downward, they strike an obstruction with the force of a battering ram.

Precautions Against Fire.

In order to guard against the ravages of the fire-fiend water pipes are carried through the sheds, and at close intervals hydrants and lines of hose are provided ready for instant use. The sheds are patrolled day and night, so that an outbreak may be caught in the incipient stage. Telephone facilities enable the watchman to get into touch with assistance, so that fire-fighting forces can be hurried up if the conflagration gets beyond the man on the spot. During the summer season, when the forest fires are raging, the patrolling forces are doubled and trebled if necessary. The necessity of these elaborate precautions will be appreciated when it is remembered that a burning shed not only represents a heavy monetary loss, but what is far more important upon such a line as the Canadian Pacific with its heavy transcontinental business, provokes a serious delay to traffic.

The distances, or "fire breaks," between the snow-sheds vary from 100 to 200 feet according to conditions. The possibilities of a snow-slide rattling down and smashing up the line in these open spaces is eliminated

by the heavy "glance" cribs or "split fences" planted on the mountain side above the line, which serve to divide the avalanche, sending it flying over the adjacent sheds. Now and again the "glance" crib does not fulfil its avowed purpose completely, so that the open part of the line becomes choked, if not damaged, but such incidents are comparatively uncommon; the "split fence" seldom fails.

A CANADIAN PACIFIC RAILWAY ROTARY SNOW-PLOUGH AT WORK.
Note the stream of snow being thrown to the side.

Nature appeared to resent the ingenuity of the engineer at the onset, since the line scarcely had been opened when it was subjected to an unusually savage assault during the winter of 1886–7. The snow-fall was terrific, 8½ feet falling within a week, while for three weeks it snowed incessantly. As a result the avalanche season was unduly lively, and the rumblings and groanings, roars and crashes, of the moving masses were continuous night and day. The conditions on the Selkirks are somewhat peculiar. There may be a heavy snow-fall. Then comes a warm spell, as the chinook wafts over the range, accompanied by heavy winter rain storms. The snow is half-melted, when a sharp spell of severe frost sets in, converting the slushy mass into ice. The line was opened for traffic before snow-shedding had been completed, and as a result many of the open stretches of side-hill excavation became filled with the debris of avalanches. When the frost gripped the debris the snow-fighters had a harassing time. Picks and shovels made no impression—the heterogeneous mass of snow, earth, rock, ice, and timber had to be blasted out in big chunks, and several days elapsed before a passage 40 feet deep, and just wide enough to admit the trains, was driven.

Yet despite all the precautions which can be taken, the snow-shed at times comes to grief, being either crushed under the terrific weight imposed or carried away and ground to splinters. Rocks and timber in the snow are responsible for this destruction as a rule. They tear an opening in the roof, when the moving snow secures a purchase upon the structure, wrenching it to pieces. The imprisoned air also plays sad havoc in such cases. Unable to escape, and becoming heavily compressed, it exercises a terrific bursting strain upon the artificial tunnel. The timber creaks, groans and bends until it cannot withstand another ounce of pressure. Then it flies, with a crashing report. Widespread damage is inevitable, and the engineer anticipates a long ding-dong battle against time in his effort to restore communication.

The capriciousness of the avalanche is extraordinary at times. On one occasion a slide swept down a steep slope from a

CLEARING A SLIDE FROM THE TRACK BY HAND.

The quantity of timber in the slide prevented the use of any type of snow-plough.

SNOW-SLIDE SCENE AT ROGERS PASS.
Looking out of snow-shed partly wrecked by slide.

point some 4,000 feet above. It hit the roof of the shed with tremendous force. The top was torn off bodily, but instead of being carried down into the valley, was hurled some 200 feet up the mountain slope above the line. The interior of the shed was filled with muck, which continued to a depth of 30 feet above the walls of the structure. When the snow-fighters appeared and buckled into the clearing task they found huge cavities or "pockets" in the débris, where the air had been caught, and, unable to escape, owing to the velocity of the slide, had been compressed. The displacement of the roof was the most remarkable feature, and to this day the engineers cannot determine decisively whether it was torn off by the snow-slide or blown up the mountain side by the bursting effort of the compressed air.

But the peril of the snow-slide soon will be a thing of the past upon the mountain section of the Canadian Pacific Railway. The authorities have now decided to escape the snow movements once and for all. The worst stretch of the danger zone is to be tunnelled at a cost of about £4,000,000. Not only will this avoid the snow-swept reaches, but it will provide the line with an easier grade.

END OF SNOW-SHED AFTER SLIDE HAS BEEN CLEARED OUT.
Observe the baulks of timber brought down by the avalanche.

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